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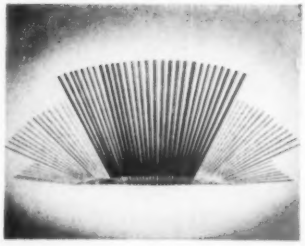

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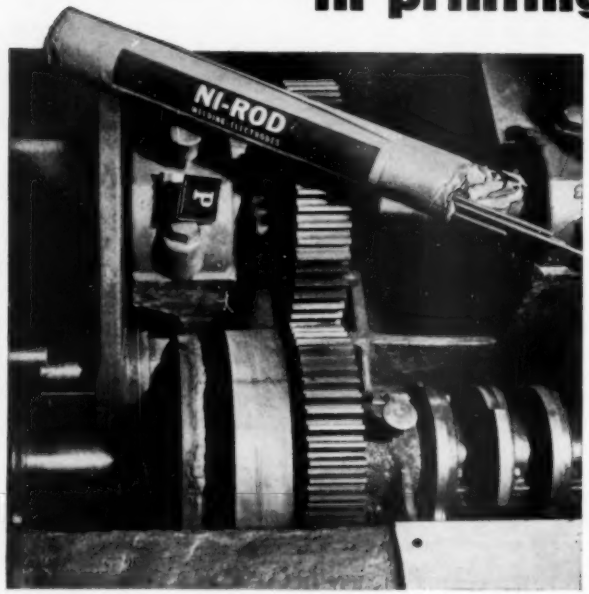
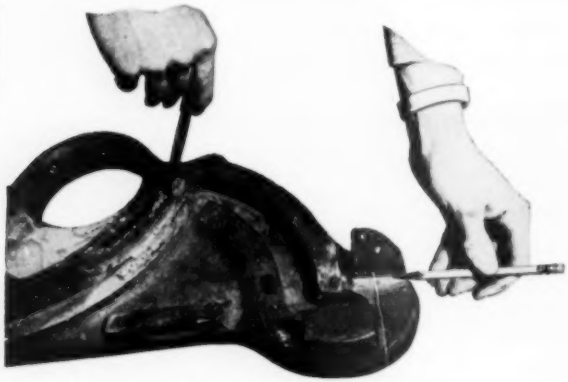


A worn cast iron cam on this Miehle vertical press was built up with beads of NI-ROD without dismantling the gear box. The welder had no previous experience with metal arc welding.



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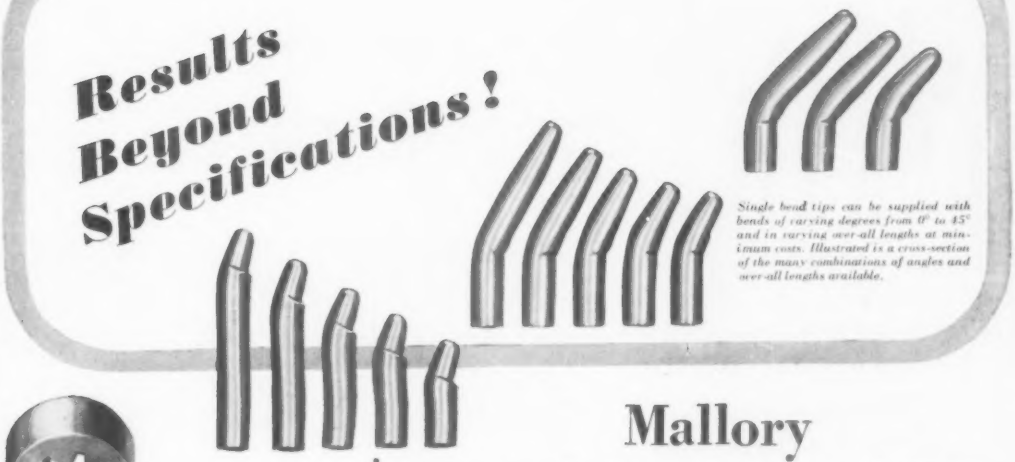

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cover: Welding inside of 142-foot tower, 13 foot, 6 in. diameter. *Courtesy Wyatt Metal & Boiler Works.*

Published monthly by the American Welding Society. Publication office, 20th and Northampton Streets, Easton, Pa. Editorial and general offices, 33 West 39th St., New York 18, N. Y. Subscriptions $5.00 per year in United States and possessions; foreign countries $7.00. Single copies, nonmembers $.75; special issues September and October $1.00; members 75 cents. Entered as second-class matter January 5, 1932, at the Post Office at Easton, Pa., under the act of March 3, 1879.

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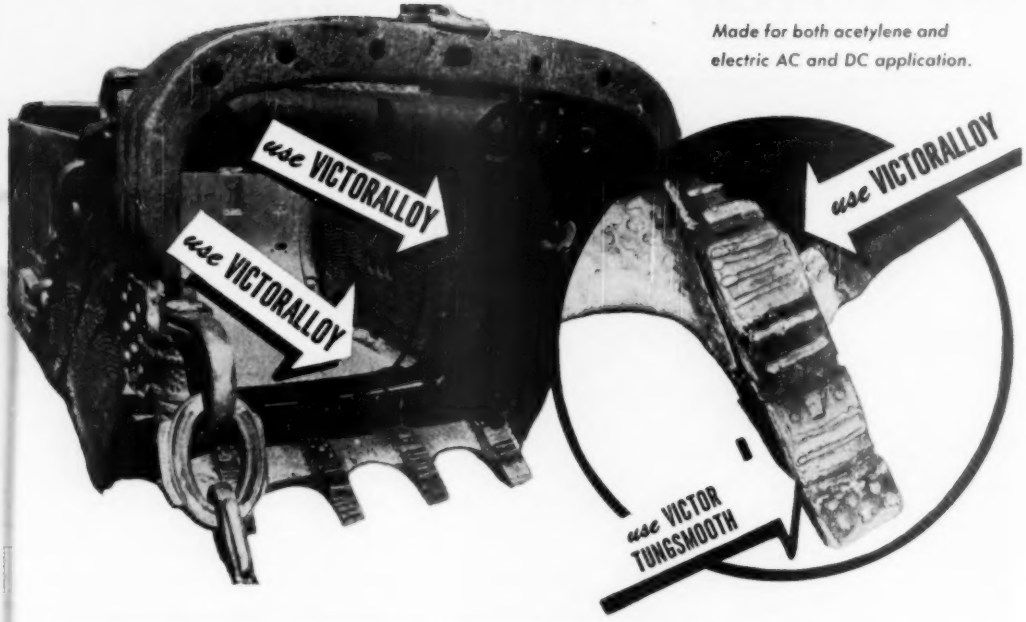

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The WELDING JOURNAL

volume 29 February 1950 number 2

Steel Warehouse Flame Shape Cutting

The electronic tracer flame shape cutting permits the steel warehouse to furnish customers prompt delivery on a complete range of steel, shapes and sizes

by W. O. Springer

INTRODUCTION—THE ESSENTIAL SERVICES OF THE STEEL WAREHOUSE

THE steel warehouse plays a dual role in our industrial economy by functioning as a quick and dependable source for steel for both the small and the large consumer of steel products. Although in volume of business handled steel warehouses account for only about 17% of the annual production of rolled steel, the number of customers served runs to about 10 times the number of steel users that buy direct from the mills. In other words, for each mill buyer who, incidentally, also buys a portion of his requirements from warehouse, there are nine others who depend entirely on warehouse stocks for the steel they need.

The steel warehouse business—and I am referring particularly to the distributors of steel who carry all steel products in stock—has grown to its present size and importance because it offers these three essential services:

1. A complete range of steels—all qualities, shapes, finishes and sizes.
2. Immediate delivery from stock—a few pounds or many tons or more.
3. Steel cut to the required size or shape—ready for use in the shop or on the job.

As this paper is devoted to but one of these services—cutting—and, furthermore, covers but one type of cutting service performed by the steel warehouse, a brief word leading up to this latest development in machine gas cutting which employs an electronic tracer may help to make more clear how this particular tool fits into our general over-all warehouse cutting service picture.

W. O. Springer is Manager, Cleveland Plant, Joseph T. Ryerson & Son, Inc., Cleveland, Ohio.

Presented at the 30th Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

BACKGROUND—OTHER TYPES OF CUTTING MACHINES

In the beginning, and this was of course many, many years ago—in the case of our company more than one hundred years ago—the steel warehouse supplied stock sizes and shapes of steel with but little, if any, cutting service included. Early cutting was a slow and laborious procedure, done largely by hand. As power machinery came into use we added cold saws to our facilities so that bars and structurals might be supplied cut to other than stock lengths. Later high-speed friction saws were put to use, greatly speeding this type of cutting. And, of course, other cutting machines became standard equipment with us, such as bar and shape shears, hack and band saws, and shears for straight and circle shearing of sheets and plates.

Some thirty years ago the steel warehouse industry went a step farther in increasing the scope of their cutting service by taking on the original radiograph and oxygraph machines for torch cutting. Our company was among the first to add machine gas cutting and over the years we have built up a large, fully equipped flame-cutting department in each of our steel-service plants.

When the electronic tracer was still in the experimental stage, we investigated the possibilities of this new development in the automatic torch-cutting field and as it appeared to hold great promise as a tool that would enable us to extend and improve our warehouse cutting facilities, we kept closely in touch as the device neared a practical reality. In 1948, when the electronic tracer as developed by Air Reduction was put into production, we placed our order for 12 of the first 20 machines to be manufactured. These are now—

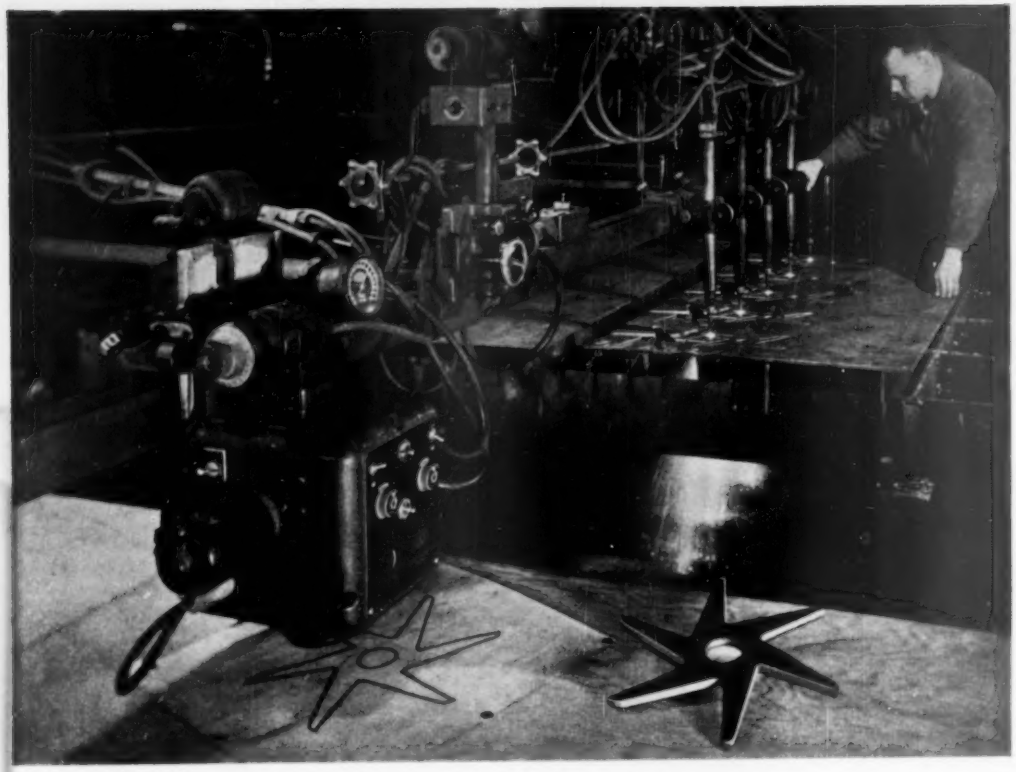


Fig. 1 The "electric eye" and 5 cutting torches in operation

The eye or electronic tracer is following the outline drawing, guiding the cutting torches which are burning 5 identical pieces in one operation. A finished piece is shown in foreground on work table

and have been for some months—in operation in our steel-service plants over the country.

THE ELECTRONIC TRACER

In describing the type of work done by this new cutting tool, a better idea of its capabilities may be gained if we first quickly review other types of torch-cutting machines which we operate and which, incidentally, are not replaced but merely supplemented by this latest development in machine gas cutting.

First we have the manually guided tracer—an economical tool for cutting single pieces or short runs—which we use for cutting both plain and intricate shapes. However, skill of the operator is an important factor when cutting highly irregular shapes, and some tolerances must be allowed when cutting duplicate pieces.

Spindle-type tracing, following a three-dimensional

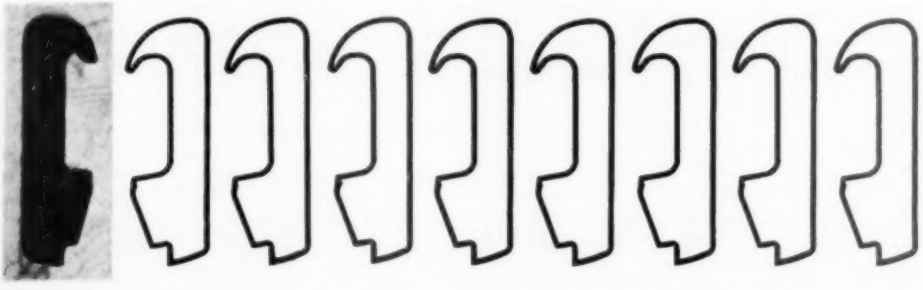


Fig. 2 Latch for trailer hitch, flame cut with the Electric Eye machine from $^{7}/_{16}$-in. plate

Size $2^{1}/_{4}$ x $6^{1}/_{2}$ in. Note multiple template used for the cutting operation

template, gives good duplication of cut shapes and is faithful to the original, but does not permit cutting very sharp corners, narrow slots and the like without somewhat complicated multiple operations which tend to increase our cutting costs. Magnetic tracing, which uses a mechanical steel cam as a template, has many of the same limitations of the spindle-type tracer. All of these machines, except the manual tracer, require the use of precisely made formed templates.

The electronic tracer uses the simplest possible templates—either a black and white outline drawing, an inked silhouette or a cut-out silhouette. It can follow the most intricate outline which will permit minimum kerf clearances, producing intricate shapes having narrow slots, slender fingers, re-entrant curves, sharp points, clean square corners—all with full precision. It operates at the cutting speed of the torch, whatever that speed may be and which depends, of course, on the thickness of the material and the shape being cut.

The electronic tracer enables us to produce parts which not only do not lend themselves to our other flame-cutting machines but which in many cases are better and more economical for our customers than parts produced by other methods such as casting, forging and stamping.

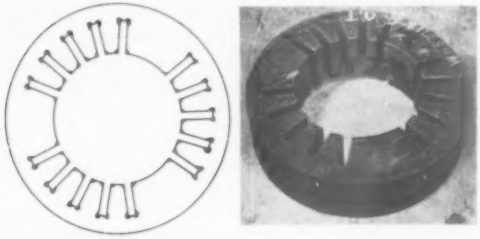


Fig. 3 Diesel locomotive part, flame cut from 6-in. plate. Diameter of piece is 25 in.

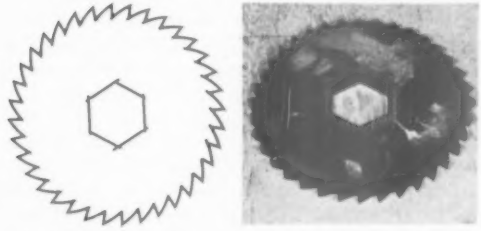


Fig. 4 Grinding wheel for grinding sand molds in foundry, flame cut from 7/8-in. plate

Diameter of the piece is 12½ in. Note sharp edges of the teeth, a type of cutting made possible by the electronic tracing device

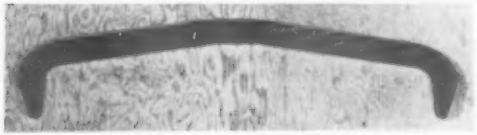


Fig. 5 Part used on a fork lift truck, flame cut from 1/2-in. plate. Size, 5 in. x 1 ft. 7 3/4 in.

The intricacies of optics, electronics and mechanics of the tracer are not particularly pertinent to this discussion as we are concerned primarily with the finished product and how this type of cutting serves the user of warehouse steel. The basic setup of the electronic tracing unit consists of a travograph (pantograph type) cutting machine, with an effective cutting area 12 ft. wide by any length, depending upon the amount of track used, a suitable tracing table, multiple torches and centralized gas controls. The travograph, with the largest cutting area available today, and with multiple torches, permits the highest degree of flexibility in the use of the electronic tracer. We cut parts of very large size in any thickness, also very large quantities of smaller parts, using the same setup. This type of installation differs from our other modern large-scale setups only in the use of the electronic tracer and its auxiliary details. The same torch procedures and methods are used, whether for single-torch operation, multiple-torch work, or stack cutting using one or more torches.

Work for the electronic tracer is scheduled by our work order department. Templates are either prepared by us or sent in by our customer as a part of his material order. We maintain a storage file where templates are retained for use on repeat orders. The

Fig. 6 Boom bar, flame cut from 1 1/2-in. plate. Size, 20 in. x 7 ft. 8 15/16 in.

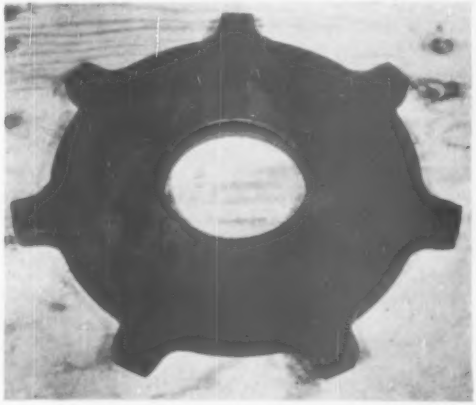


Fig. 7 Sprocket for conveyor, electric eye flame cut from 1 1/2-in. plate. Size of piece, 26 1/4 in. diameter

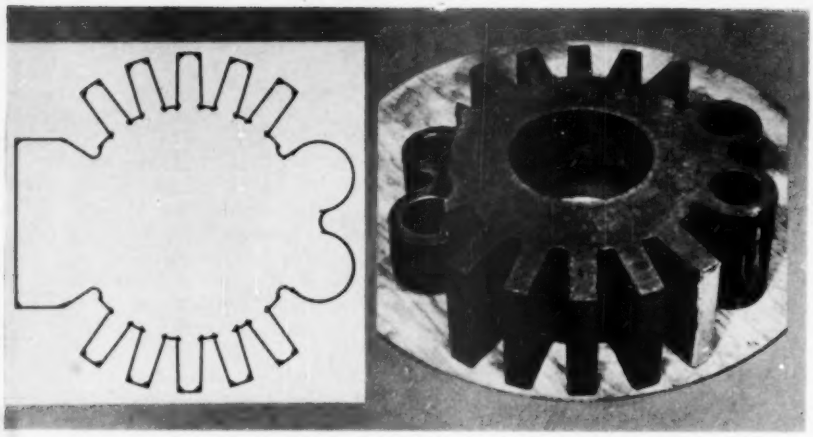


Fig. 8 Part for Diesel locomotive, flame cut from 7-in. plate

Note template provides for electronic tracer cutting of the outside of the piece, which includes the teeth with square corners. Holes were cut with a radiagraph machine. Side cutting at holes on left of piece greatly speeded production by eliminating hogging off the metal at this point. The diameter of this piece is 23¼ in.

templates may be either cut-outs or drawings. A drawing is preferred as it is more durable, more easily stored and handled safely, and since it is less subject to damage along the tracing line is more likely to give long-lived accuracy.

Templates are prepared on the same dimensional basis as for other types of tracers, that is, with due allowance for kerf width but with no allowance necessary for the dimensions of a tracer spindle or the template itself. The only special detail of the drawing or cut-out is a little pointed extension which is used on corners where absolute squareness is desired. This takes care of a slight rounding inherent in the mechanism at such points, which on most work is not objectionable. Where cut-outs are made, they are laid out on heavy white or off-white paper, and carefully cut out with scissors. Drawings are made by standard drafting procedure, with at least 1/8-in. solid black line on the tracing contour.

One of the economies possible with the electronic tracer is the "nested" or "interfitted" template, which permits the cutting of several parts from one drawing. The space between outlines can be very small in such cases as allowance need only be made for kerf width between parts. As a result, work can be so interfitted that set-up time is saved. For example, we recently supplied a customer with three roughly concentric circular parts from the gross steel area which would ordinarily have been required for the largest of them, the third part being obtained from what would have been the internal scrap of the second. Without the inter-nested template and the electronic tracer, this particular job would have required three separate formed templates.

From an over-all standpoint, the use of the electronic tracer permits us to cut more intricate shapes on a production basis than is possible with other automatic torch-cutting equipment, and to produce them more quickly. These features of the machine are important to our customers because new fields are open to them—flame-cut shapes can be employed for an even wider range of products.

FLAME CUTTING AND WELDING—A MODERN PROCESS OF STEEL FABRICATION

Flame cutting and welding form a team that is hard to beat in the fabrication of many types of fixtures and equipment, notably heavy units such as road building machinery, cranes, presses and ship parts. Component parts are shaped from strong rolled steel by flame cutting, at much lower costs than they could be produced by any other method. The parts are then assembled and welded together to form a portion of or the whole of the completed unit.

Flame shaping of steel has been spoken of at times as one of the more important alternate methods of fabricating parts. The word "alternate" may bring to mind "substitute" and this in turn might conceivably lead one to believe that flame cutting is to be considered only as a temporary means of securing shaped parts in emergencies or when other methods fall down for one reason or another. Nothing, of course, could be farther from the truth. The chief consideration should be the characteristics of the piece produced, along of course with the cost and speed of procurement. Experience has shown that parts

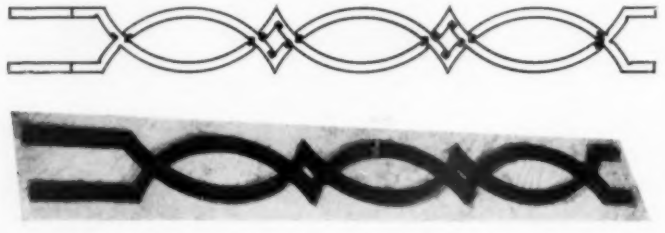


Fig. 9 Ornamental iron railing, flame cut from 3/8-in. plate

Note clean, sharp corner cutting which is made possible by the electronic tracer. Size, 4½ in. x 3 ft. 1 in.

shaped by flame cutting and joined by welding offer not merely an alternate method but, in a growing number of cases a more desirable method of fabrication.

The rapid growth of flame cutting as an industrial tool is due largely to the development of mechanized or machine-cutting equipment that is fast, accurate and extremely versatile. The electronic tracer, of course, represents the newest development in this field. When flame cutting or flame shaping of steel is employed there is no investment in expensive presses, dies, patterns, etc. In fact, for the average user no investment of any kind need be made to take advantage or to utilize the flame-cutting process. Flame-cutting service is now available from many sources of which the steel warehouse is best known. And if I may be permitted to refer to our own company, I can state freely that the service is very quick and dependable.

Unless flame cutting is employed quite extensively in production work, there are some very good reasons why it is generally more practical and economical to have flame-cut shapes produced outside your own shop. The most important reason is the cost of make-ready. This involves the movement and placement of material for cutting, and the removal of cut material to the next operation or to a place of storage until it is needed. Time studies have shown that the portion of the cycle devoted solely to cutting is but a small fraction of the complete floor-to-floor time. Thus, while the cutting operation alone may indicate that worth-while economies are being effected, the total cost—including cost of the equipment—may be out of line when handling and other costs are included.

Because of the nature of the flame-cutting equipment it cannot always be installed at the most logical spot in a production line. Usually a place apart is required where the open flame, heat, etc., do not present a fire hazard and do not interfere with other operations. Until such time as the volume of work requires it and an efficient lay-out can be arranged, the average metal working plant, machine shop or fabricator will be better off to draw on outside sources for flame-cut shapes. The routine involved in this type of cutting has been reduced to the simplest form by the steel warehouse. You can depend on this source to produce flame-cut steel shapes promptly and at low cost.

Discussion by T. H. Ayling

Mr. Springer mentioned that the electronic tracer reproduces the outline of the black-and-white template "with full precision," and perhaps some amplification of this aspect of its operation may be of interest in connection with his paper.

The tracer steering motor is actuated by the changes in intensity of a projected spot of light, according to the proportion of that spot which is reflected from a white surface. If the intensity of the light changes, even a little—as it does when the contour of the template changes—it is enough to actuate a thyratron, which causes an instantaneous reaction in the steering motor, to correct the deviation and restore the light spot to its balanced course. This action is so designed that it will be smoothly continuous in case of a curve; abrupt in case of a corner; and inoperative on a straight line in normal operation. It is so fast and precise that in watching the light spot follow the line there is not only no perceptible lag whatsoever, but the spot almost seems to anticipate a change of course. This speed of reaction is the key to the accuracy and smoothness of the device. There are also numerous special arrangements in the highly advanced electronic circuits to eliminate any tendency to "hunt"; to permit an adjustable range of sensitivity; and to allow corrections to be made for unavoidable incident light. These devices increase the reliability and usefulness of the tracer, preserving its inherent precision.

In order to obtain full value from the built-in accuracy of the unit, good template practices are also essential. As Mr. Springer has indicated, there are two basic methods in use—drawings and cutouts. Since it makes little or no difference to the tracer which is used, it is entirely a question of facilities, convenience and the degree of durability desired. Where drawing-room facilities are ample, ink outlines will usually be preferred—and where a skilled hand with the scissors is available, cutouts will be less costly and the choice for most work.

Regardless of which type is used, it must be realized that the accuracy of the cut is far more dependent upon the template than upon the tracer. A corner chopped off by the scissors on paper will be chopped off by the torch on the steel. Even with the requirement of care and accuracy in their preparation, however, the paper templates are far less expensive to prepare and use than conventional three-dimensional pieces. Given the same careful, intelligent operation as other modern production tools, the electronic tracer will perform reliably and accurately.

T. H. Ayling is Cutting Specialist, Technical Sales Division, Air Reduction Sales Co., New York.

Discussion by W. Begerow

Mr. Springer's paper relating to the extensive use of electronic tracing devices with flame-cutting machines in steel warehouses should do much to dispel the thought that this tracing device is a mysterious or complicated unit. Actually it is quite simple. Basically this tracing device is nothing more than the familiar manual tracing device equipped with a motor which rotates or turns the manual tracer about its vertical axis. This rotation of course is either clockwise or counter-clockwise. It is well known by now that the automatic turning or steering of the tracing wheel is accomplished by projecting a spot of light, approximately $^1/_{10}$ in. in diameter, on the template or surface being traced. This light spot is produced from an independent light source projected through an optical system. The rays of light, reflected from this light spot, are picked up by photoelectric tubes. These tubes generate an electric current which when amplified causes the steering motor to run and consequently turn the tracer. If the light spot is projected on a white area, the steering motor will run in one direction; if projected on a black area, the motor will run in the opposite direction. However, if one half of the light spot is projected on a black area and one half on a white area, the steering motor will not run and no turning takes place. In tracing a template outline, the light spot continually seeks to center itself by turning in one direction or the other. This turning motion is transmitted to the tracer, thus producing automatic following. The unit is equipped with two additional motors. One, a governor controlled motor which drives the wheel which moves the unit over the template surface. This motor, by means of finger tip control, can be readily adjusted to operate over a wide range of speeds. The second is a motor which raises and lowers the unit in relation to the tracing table thus providing an all electric unit.

The chief advantages of the electronic tracer may be summed up as follows:

1. Permits cutting of shapes or outlines impossible by other means of tracing.
2. Accuracy comparable to that obtained with machined templates is possible.
3. Lower cost in the preparation of templates.
4. Ease in changing template outline or dimensions.
5. Decrease in time lag between template preparation and cutting.
6. Templates are easily stored.
7. Chain cutting—ability to cut a number of pieces by one continuous cut.
8. Fully automatic operation of tracer.
9. Reduction in operator fatigue.

W. Begerow is Research and Development Engineer, Development Division, Air Reduction Lab., Murray-Hill, N. J.

The Icosasphere

A method for predicting the flow or displacement in plates which are formed and drawn and the application of method to forming spherical tanks

by J. O. Jackson

RESEARCH Report 7815, recently published by the Pittsburgh-Des Moines Steel Co., Pittsburgh, Pa., describes the development of a new method for predicting the flow or displacement of materials in plates and sheets which are bent, formed or drawn in such a manner that plastic flow occurs. The report also describes one application of this method to the layout of plates forming spherical tanks.

This method of predicting plastic flow provides a new tool to help the research worker obtain solutions of layout problems in a much shorter time than would be possible by the cut and try method. This method consists of forming the desired object of a suitable plastic material, softened by heat and allowed to cool between dies, or otherwise restrained to the desired shape. The edges of the piece are then trimmed to the outline required, after which the trimmed piece is relaxed by heating to the softening point when it will flatten and assume the outline of a properly shaped flat piece, which, if dished or formed to the proper shape, will flow plasticly to produce a finished piece of the proper shape.

Figure 1 illustrates such a determination being made in the research laboratory of the Pittsburgh-Des Moines Co., at the Mellon Institute of Industrial Research in Pittsburgh. The operator has just pressed a piece of

J. O. Jackson is Vice-President, Engineering and Research, Pittsburgh-Des Moines Steel Co., Pittsburgh, Pa.

Fig. 1 Pressed pieces of Plexiglas being checked for accuracy

Plexiglas to form one of the plates of a spherical shell and is checking it for accuracy. The pressing form and other pressed pieces may be seen in the picture.

This process is applicable to any formed work where plastic flow is involved, as, for example, spherical tanks; wind tunnel flares, nozzles, contraction pieces; hemispherical, elliptical and toroidal tank bottoms; and in any other dished, pressed, drawn or warped plate work.

The first application of this method was to determine the shape and arrangement of plates to form a spherical tank shell with a minimum amount of scrap loss and a minimum number of feet of welded seam. Spherical tanks have been made with several plate layouts. The most common layout is known as the "orange peel" design and usually consists of a top and bottom saucer with one or more courses of approximately vertical plates in between. These vertical plates are wider near the center of the sphere and taper toward the top and bottom so that they resemble orange peels. Since these plates are tapered, two can be cut from one rectangular plate, which reduces the scrap. However, when this is done, the finished sphere plates are much narrower than the economical width which results in a considerable increase in the footage of welded seams over that resulting if only one sphere plate is cut from each rectangular plate. However, if plates of maximum width are cut singly to form the separate plates, the amount of scrap is excessive.

The cubical layout was developed some years ago in which rectangular plates were laid out on the sides of an imaginary rubber cube circumscribed by a sphere. The cube is then expanded until its faces touch the spherical shell. In expanding the cube to fit the sphere, all of the edges of the plates will become curved, but the plates will be more nearly rectangular in shape than the orange-peel plates and the amount of scrap will in most cases be reduced.

In the study made by the plastic model method, several layouts were considered, were quickly made on the dished plastic, relaxed and the shape of the relaxed plates measured to determine the best layout.

Any layout of plates for a sphere which is to have a repeating pattern must be based on the faces of one of the regular polyhedrons of which there are but five. These are the tetrahedron with four triangular faces; the hexahedron, or cube, with six square faces; the octahedron with eight triangular faces; the dodecahedron with twelve pentagonal faces and the icosahedron with twenty triangular faces. The icosahedron may be built without scrap loss for the triangles may be alternated and cut from a rectangular plate without any waste. Four adjacent faces of an icosahedron may be flattened and they will form a parallelogram. Five of these parallelograms will form the entire surface of an icosahedron. These facts suggested that if a spherical shell were formed by five parallelogrammic units, each of which represented four adjacent triangular faces of the icosahedron expanded to the spherical

Table 1—Comparison of Required Material and Number of Feet of Seam for Different Sphere Layouts

Layout	No. of Plates	Ordered Excess(1) Sq. Ft.	Ordered Excess(1) Per Cent	Feet of Seam
10 Ft. Diameter Spheres				
1. Icosasphere	5	57	18	83
2. Orange Peel(2)	6	125	40	96
3. Cube Layout	6	62	20	70
20 Ft. Diameter Spheres				
4. Icosasphere	20	221	11	423
5. Orange Peel(2)	18	670	34	368
6. Orange Peel(3)	32	447	23	600
7. Cube Layout	18	367	19	420
30 Ft. Diameter Spheres				
8. Icosasphere	48	886	11	1418
9. Orange Peel(2)	40	3460	44	1948
10. Orange Peel(3)	50	1609	21	1903
11. Orange Peel(4)	32	860	11	1068(Shop) 1265(Field) 2325(Total)
12. Cube Layout	30	1824	1b	1279

Notes. 1. Ordered excess is area ordered less area of sphere expressed in square feet and in per cent of sphere area.
2. Plates cut one sphere plate from one rectangular plate.
3. Plates cut two sphere plates from one rectangular plate per Sketch A.

Sketch A

4. Plates cut diagonally in half and rewelded in shop per Sketch B.

Sketch B

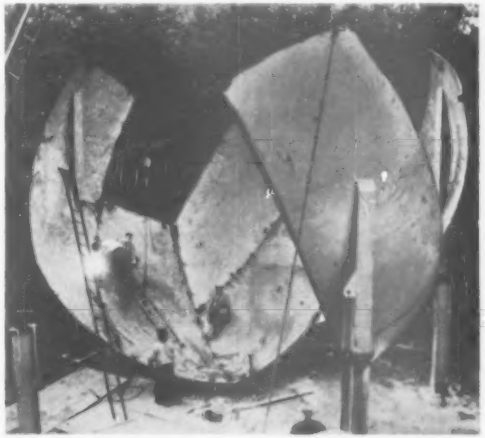


Fig. 2 Showing erection and tack welding of the Icosasphere

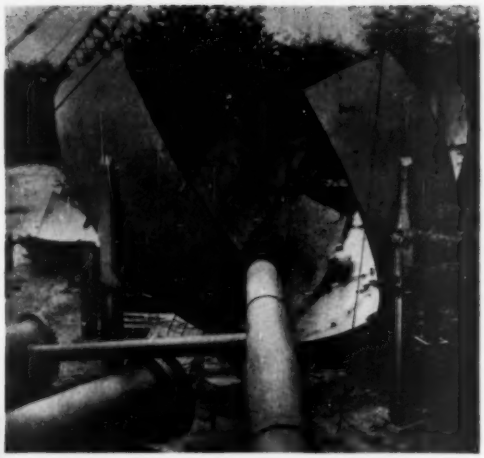


Fig. 3 Showing erection of the Icosasphere in the early stage. Note rectangular shape of plates

surface, the layout might be the best one possible from a standpoint of scrap loss. A sphere may be divided into twenty equilateral spherical triangles, but it is not possible to divide the surface of a sphere into more than twenty equilateral triangles for the same reason that it is not possible to have a polyhedron of more than twenty faces which are identical.

The Icosasphere is then a sphere laid out along the expanded lines of four adjacent faces of an icosahedron. Five plates cut the proper shape and dished will form a complete sphere. These plates may be cut from one rectangular plate with a remarkably small scrap loss. As the size of the sphere increases, it is necessary to further subdivide the five parallelogrammic units, and designs have been prepared based on subdividing each side into two, three, four and eight subdivisions. Table 1 shows the excess steel that is required to be purchased, expressed in square feet and in per cent of the area of the sphere, and also the number of feet of joints, usually welded joints, required for each layout and for three sphere diameters. If the cost per foot of joint is added to the cost of scrap for any assumed thickness for the various layouts, the most economical layout may be determined.

Figure 2 shows the erection and tack welding of the

Fig. 4 The completed Icosasphere

This sphere is 32 ft. 5 in. inside diameter, 1/2 in. thick and is made of only 20 shell plates. It is supported on 5 columns

plates forming an Icosasphere which was 32 ft. 5 in. inside diameter. The plates were 1/2 in. in thickness. The shell is formed of only twenty plates; it is supported on five columns.

Figure 3 shows the appearance of the shell during erection from the other side and illustrates the large pipes which connected the sphere to the supersonic wind tunnel test chamber.

Figure 4 shows the completed sphere. The sphere was erected in a single day, but the welding of the seams took many days. After completion, the shell was tested to 100 psi. hydraulic internal pressure which it withstood satisfactorily. The shell was designed for an external working pressure of one atmosphere, or 14.7 psi. The high-internal pressure test of about 6.8 times the external working pressure of the sphere was for the purpose of removing flat spots and rounding out the surface of the sphere so that it would more effectively resist the external pressure.

The design and construction of the Icosasphere is covered by patent applications owned by the Pittsburgh-Des Moines Co.

Flux Densities for Magnetic Particle Inspection

A method is described for determining the flux density in steels which are magnetized with direct current. Practical application is shown between flux density-depth values and current required to locate artificial defects

by T. E. Hamill

Abstract

Method is given for determining the flux density, at the surface and up to 5 in. below the surface, in steels which are magnetized with direct current. Results are given on low-carbon steels (0.20 to 0.30 C) of varying shapes and sizes. Flux density-depth values are given on round bars, varying in size from $^3/_4$ to $7^1/_2$ in. diameter, plates $^1/_2$ to 6 in. thick and four types of weld joints made from steel plates $1^1/_4$ and 3 in. thick, using currents ranging from 200 to 2000 amp. Stress relieving the weld specimens at 1175° F. shows an average increase in flux density of 75–100% over that obtained in the as-welded condition. Flux distribution was studied on one end of a large steel block, 6 x 12 x 3 in., when magnetized with 500 and 2000 amp. and equiflux lines were drawn. Flux density and orientation values are given on an irregularly shaped steel casting. The effect of electrode spacing between 4 and 37 in. was studied on a 2-in. diameter bar and a plate 3 x 36 x 24 in. Practical application of method on tube section, 7 in. O.D. x $^3/_4$-in. wall thickness, shows the relation between flux density-depth values and current required to locate artificial defects at various depths below surface, when magnetized by direct and indirect methods. The uniformity of four gaussmeters, ranging in size from 100 to 1000 gausses and in age from new to 2 yr. old, is given.

INTRODUCTION

THE demands of the armed services during World War II for a dependable product resulted in the expansion of old and the development of new methods of nondestructive testing and the writing of numerous specifications. The requirements of many of these specifications often necessitated close surveillance of the product during manufacture and rigid inspection of the completed product. One of the methods of inspection which was developed and its use increased tremendously during the last war was that of magnetic particle inspection. This was due to a greater knowledge of its use, applications and limitations. It was found that the location of defects by magnetic particle inspection depends, primarily, on (*a*) kind of current, (*b*) flux density in the region of the defect, (*c*) orientation of the magnetic field with respect to the defect, (*d*) dimensions of the defect and (*e*) depth of the defect below the surface: secondary factors found to have an effect on the pattern were (*f*) shape of the piece and (*g*) residual magnetism of the metal undergoing test.

The kind of current used is probably the most important variable and depends on whether surface or subsurface defects are to be located. Alternating current is used only for locating defects on the surface, or within $^1/_8$ in. of the surface. Direct current is used for locating surface and subsurface defects. The flux density in the part is of next importance, since the effectiveness of the magnetic particle test will depend on sufficient flux reaching the area. The use of excessive or insufficient field strength may lead to the missing of defects, showing nonobjectionable or false ones, or masking real defects. The desirable range of magnetization is probably between the maximum permeability region and some point well below the saturation of the steel; and satisfactory results have been obtained at 30 to 80% of the saturation point.[1] The need for a field gage, which can be calibrated, for measuring the amount of flux density and orientation of the flux in the part undergoing test was stated in several recent articles.[2–5] Various field gages were made and marketed to measure the value at the surface and several articles have been printed showing the results. Our experience with some of these meters has been very disappointing. The values obtained were not reproducible, their range was limited and they could only be used on a smooth flat surface. Furthermore, these meters measured, or attempted to measure, only the flux at the surface and not below the surface. The rate at which the flux density decreases below the surface is not known except for a few simple shapes. It is important in all shapes for the determination of subsurface defects.

It is the purpose of this paper to describe an instrument for measuring the flux density of a part, not only at the surface but several inches below the surface, and show how the flux is affected by some of the variables that are encountered in magnetic particle inspection. The method in itself will probably be called destructive, since it involves drilling holes, $^1/_{10}$ in. in diameter, $^1/_2$ to 1 in. in depth, at the locations where the flux is to be measured. However, in many cases the piece can be salvaged by chipping the hole large enough to reweld, or

T. E. Hamill is Welding Engineer at the U. S. Naval Gun Factory, Washington, D. C.

The opinions are those of the author and are not necessarily the official views of the U. S. Navy. Presented at the Thirtieth Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

repair may not be needed. Furthermore, it should not be necessary to apply the instrument to each individual part where many duplicate parts are being inspected. By surveying the pilot part a procedure can be developed to magnetize the part properly within the desired range, which can be used on all of the pieces.

INSTRUMENTS AND METHOD OF TEST

The meters used in this investigation are proprietary instruments that have been on the market for over 2 yr. They are made in various ranges, 0–100, 0–500 0–1000, 0–2500 and 0–5000 gausses, and have a guaranteed accuracy of 5%. Each meter is furnished with a calibration magnet. These gaussmeters are miniature magnetometers consisting of a 2-in. round case with a hollow bronze rod, $1^1/_4$ or 5 in. in length and 0.090 in. diameter,* protruding from the back. At the lower tip of the rod a tiny permanent magnet of Silmanal, approximately 0.125 in. long and 0.04 in. diameter, is mounted on a jewel about 0.085 in. thick. The magnet is connected to a pointer in the case by means of a shaft and the pointer is normally held to zero position on the scale by means of a torque spring. When the rod is placed in a magnetic field the poles of the magnet try to line up with the flux and if the instrument case is rotated about the shaft until the pointer is 90° away from its initial direction, the magnet is at right angles to the measured flux and the flux density is read on the scale. If the case is rotated about the shaft until the pointer is zero on the scale, the pointer will indicate the flux direction. Some of the instruments are shown in Fig. 1.

The size of instrument used in most of the tests was the 0–500 meter with the 5-in. rod length. The scale was graduated in 10 gausses and could be read to an accuracy of 1 to 2 gausses, while the flux could be examined at any depth up to the full length of the rod.

The method of test consisted in drilling holes, 0.105 in. diameter, into the material to the depth desired and inserting the rod into the hole at various depths. The depth of the rod was regulated by using a brass bushing containing an adjustment screw, which was tightened at the desired rod length. The length of the rod was measured by means of a scale graduated in 0.01 in., but a depth gage which could be read more accurately was used later. The instrument and bushing were then rotated in the hole until the maximum reading was obtained. The current was supplied from a K.Q. 4.5 Magnaflux Unit, without surge, and a 300-amp. motor-generator welding machine converted to magnetic testing. The amount of current from the K.Q. 4.5 machine was controlled by means of an 8-point rheostat. Fine adjustment was not possible on this equipment and readings varied 10 to 50 amp. from that desired, depending on the resistance of the circuit. The pieces were magnetized by applying current through two $1^1/_2$-in. diameter copper lugs, which had been screwed into the piece except when the welding machine and prods were used. Figure 2 shows the setup used in making most of the tests.

The 0.105-in. diameter holes were used in all of the tests because smaller holes produced a tight fit when the flux was measured at depths greater than 3.0 in. If meters having 1.25-in. instead of 5.0-in. rod length were used, smaller holes such as 0.096 in. diameter could be used and different results may be obtained. However, a 7.0-in. diameter, welded, low-carbon steel ring, made from $^3/_8$-in. diameter bar stock that was magnetized by wrapping it with copper wire and applying between 900 and 1800 amp. turns, showed no difference in flux readings between the 0.105- and 0.096-in. diameter holes. A 0.093-in. diameter hole in the same ring gave about 7.0% lower readings than with the larger holes.

The correction factor applied to all readings was the distance from the bottom of the rod to the center of the magnet. This was found to be about 0.15 in. for all of the gaussmeters except the 100 meter. The magnet in this meter was approximately 0.062 in. longer than those on the other meters and a correction factor of 0.18 in. was used for this meter.

CHEMICAL COMPOSITION AND STRESS RELIEF TREATMENT OF STEELS

The chemical compositions of the steels used in the

* Recently some of these meters have rods of 0.075 and 0.052 in. diameter.

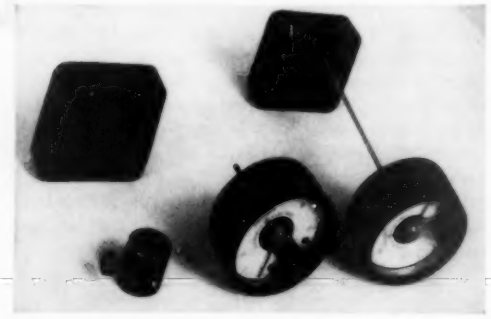


Fig. 1 Some of the gaussmeters used in the investigation with their calibrating magnets and the brass bushing

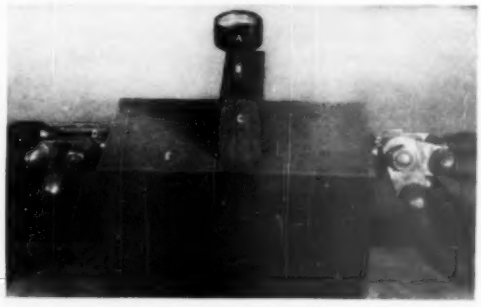


Fig. 2 Setup used in taking flux-depth measurements in a block 6 x 12 x 12 in.

A, gaussmeter; *B*, brass bushing; *C*, wooden block; *D*, electrode connections; *E*, test block

Table 1—Chemical Composition of the Steels

Shape	Size	Elements C	Mn	Si	S	P	Ni	Cr	Use
Rounds	3/4 to 7 1/2 in. diameter	0.20-0.29	0.46-0.95	0.02-0.17	0.040-0.050	0.020-0.030	...	...	Flux depth
Plates	1/2 to 6 in. thick	0.22-0.30	0.32-0.46	0.06-0.25	0.033-0.042	0.020-0.025	...	...	Flux depth
Deposited weld metal	.....	0.09	0.35	0.10	0.026	0.030	...	...	Weld tests
Plate	3 x 24 x 36 in.	0.25	0.47	0.13	0.042	0.025	...	...	Electrode spacing tests
Round	2 in. diameter	0.17	1.52		0.16	0.022	...	...	Electrode spacing tests
Plate	6 x 12 x 3 in.	0.30	0.47	0.06	0.041	0.025	...	...	Equiflux tests
Casting	40 x 22 x 1 1/2 in.	0.25	0.58	0.36	0.020	0.029	0.40	0.23	Irregular shape casting test
Tube	7 in. O.D.	0.14	0.28	0.13	0.035	0.020	0.05	0.05	Depth of defect test

investigation are given in Table 1. All of the steels are low in carbon content except the 2-in. diameter round which was used in the electrode spacing tests. This steel was the free machining type, high in manganese and sulphur content.

All of the steels except the weld specimens were stress relieved before test at 1175° F. for a minimum of 1 hr. per inch of thickness and furnace cooled. This treatment was believed satisfactory for removing at least 90% of the residual stresses. The weld specimens were studied in the as-welded and stress-relieved conditions.

RESULTS OF TESTS

Rounds and Plates

Five bars, 3/4, 1 1/4, 2, 3 1/2 and 7 1/2 in. in diameter were cut 12 in. long and holes drilled on each end at the center for electrode connections. Three holes, 0.105 in. diameter, were drilled 2, 6 and 10 in. from one end up to a maximum depth of 5 in. Two hundred, 500, 1300 and 2000 amp. were passed through each bar and readings taken at various depths in each hole. The results obtained on the center hole, i.e., 6 in. from one end, of the 3 1/2-in. diameter bar is shown in Fig. 3. Some of the curves obtained on the center hole of the rounds are given in Fig. 4, while the maximum flux densities, are shown in Fig. 5. The results show a decrease in flux density with increase in diameter of the bars.

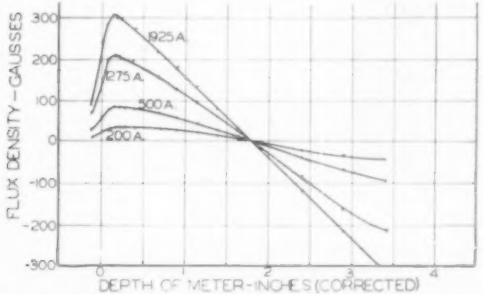


Fig. 3 Flux density-depth curves obtained on a 3 1/2 in. diam. round

Measurements were taken in the center hole and the electrodes were connected at the center of each end of the bar

Five specimens, 12 in. square, were cut from plates 1/2, 2, 3, 4 3/4 and 6 in. in thickness. Three holes, 0.105 in. diameter by 1 to 5 in. deep, were drilled 2, 6 and 10 in. from one end along the center line of the thickness with electrode connections at mid-thickness of each end. Flux density readings were obtained in these holes at various depths, using currents of approximately 200, 500, 1200–1300 and 1900–2000 amps. The results obtained on the center hole of some of the plates are given in Fig. 4, while the maximum flux density is given in Fig. 6. The results show an increase in flux density with increase in thickness of the plates.

The location of the peak point for the various sizes of rounds and plates tested at currents between 200 and 2000 amp. are given in Fig. 7. The peak point for the rounds occurred between 0.04 and 0.10 in. for all currents, but reached a maximum depth of 0.80

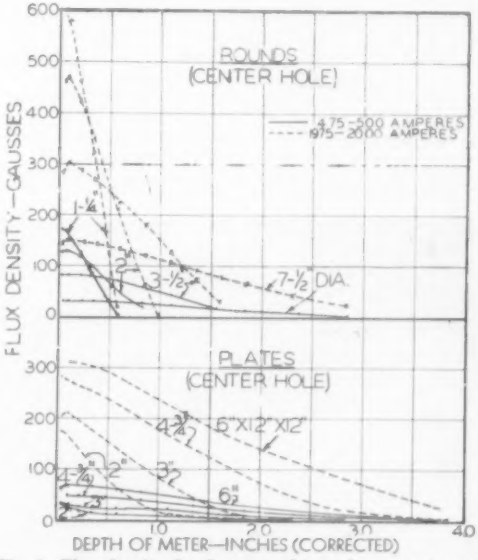


Fig. 4 Flux-density depth curves obtained on ronnds and plates of various diameters and thicknesses

The rounds were 12 in. long, the plates 12 in. long by 12 in. wide and the electrodes were connected at the center of each end of the rounds and at one end of the plates where the measurements were made

in. at the low currents for two sizes of plates. All other types of materials, such as the welded specimens, casting, tube, etc., that were investigated by the direct continuous method showed the peak point to occur between 0.04 and 0.225 in. below the surface. With a correction factor of 0.15 in. this means that the peak point in these materials occurred when the gaussmeter was inserted in the hole to a depth $^3/_{16}$ to $^5/_8$ in.

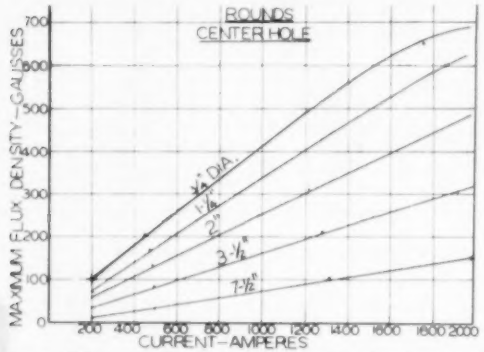


Fig. 5 Effect of current on the maximum flux density of various sizes of rounds

Electrodes were connected at the center of each end of the 12-in. long specimens

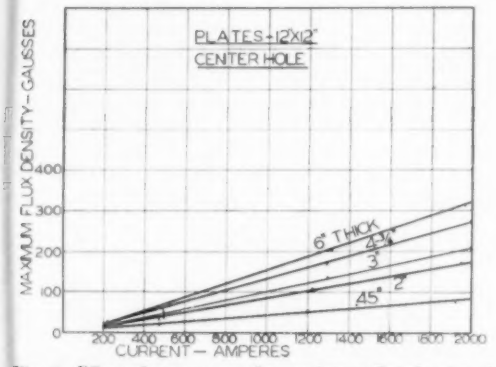


Fig. 6 Effect of current on the maximum flux density of various thicknesses of plates

Plates, size 12 in. long by 12 in. wide, were magnetized at mid-thickness point at the end at which readings were taken

Weld Specimens

Eight welded joints were prepared from 0.25% carbon-steel plates, $1^1/_8$ and 3 in. thick. Four types of joints were made from each size of plate. They were: (1) double vee butt, (2) double fillet tee, with fillets equal to the size of plates, (3) double bevel tee and (4) double fillet corner joints, with inner welds equal to one-half the thickness of the plate. The plates were 18 in. long and 6 in. wide, except the bottom plate of the tee joints which were 12 in. wide, and were welded with A.W.S. E6020 electrodes. Three holes, each 0.105 in. diameter, were drilled in the center of one weld of each specimen, $1^1/_2$ in. from each end and 9 in. from one end. All holes were drilled through the center of the weld toward the root. Thus, the holes were drilled at angles of $22^1/_2$ and 45° with respect to the bottom plates of the double bevel tee and fillet tee joints, re-

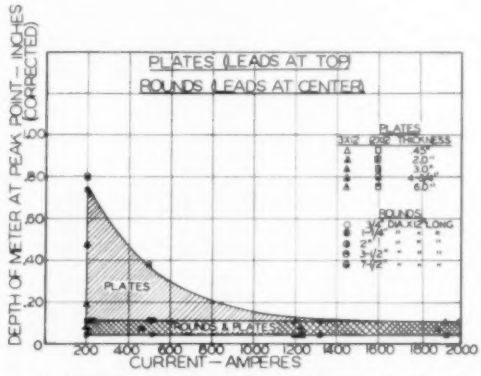

PLATES (LEADS AT TOP)
ROUNDS (LEADS AT CENTER)
DEPTH OF METER AT PEAK POINT – INCHES (CORRECTED)
CURRENT – AMPERES
PLATES
ROUNDS & PLATES

Fig. 7 Location of the peak point in the rounds and plates of various diameters and thicknesses

Fig. 8 Weld specimens used for flux density-depth measurements

Holes at ends of specimens were used for electrode connections and ground spots on welds for prod locations

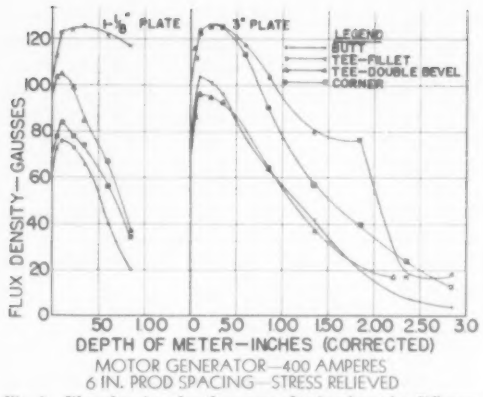


Fig. 9 Flux density-depth curves obtained on the different type and sizes of weld specimens

spectively, and at 90° with respect to the surface of the weld in the other two types of joints. The surface around each hole was cleaned 1 in. in diameter by 0.01 in. deep to obtain accurate measurements.

The specimens were magnetized by applying currents, ranging from 200 to 2000 amp., at the ends. The center portion of the specimens were also magnetized with 400 amp. from a motor-generator machine using prods 6 in. apart and readings were taken on the center hole for comparison. The specimens are shown in Fig. 8, while some of the results obtained are shown in Fig. 9. The outer holes on the weld specimens were primarily used to determine if the flux was uniform at each end, and to find the ratio between these readings and those obtained at the center. In general, the flux at the outer holes was about 100% greater than that at the center hole, but the relationship between the different types of welds is about the same as was found on the center hole using the prods with 6 in. spacing. The latter test showed the maximum flux to vary between 38 and 79 gausses for specimens prepared from the 1 1/8-in. plates and between 47 and 79 gausses for the 3-in. plates in the as-welded condition. Most of the curves were irregular in shape and there was no definite relation between the different types of joints. Increase in the amount of current from 200 to 2000 amp. increased the quantity of flux in each weld specimen, but not always at the same rate.

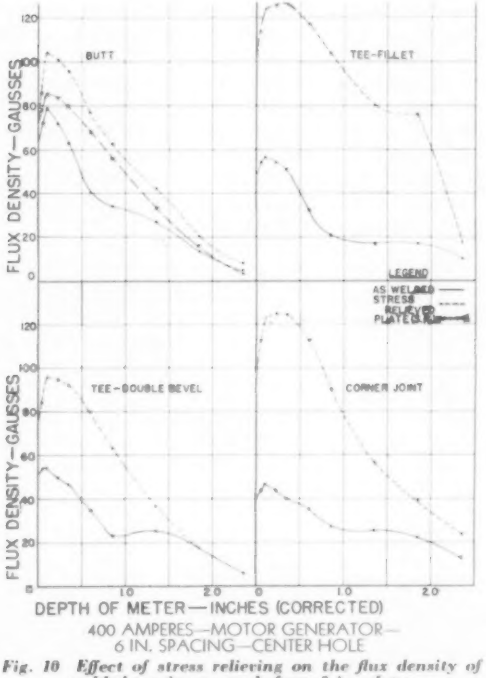


Fig. 10 Effect of stress relieving on the flux density of welded specimens made from 3-in. plates

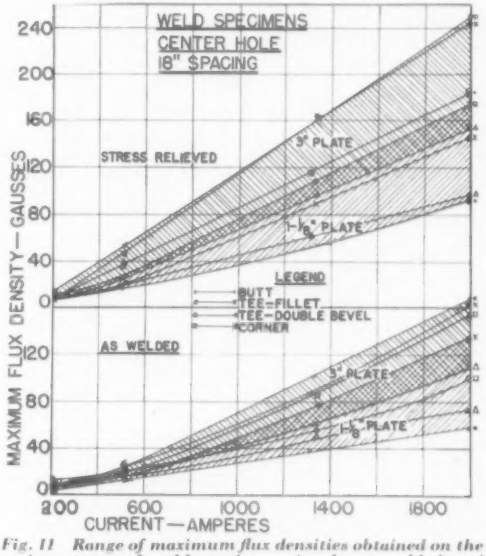


Fig. 11 Range of maximum flux densities obtained on the various types of weld specimens in the as-welded and stress-relieved condition

Effect of Stress Relieving. The eight welded specimens were stress relieved at 1175° F. 4 for hr. and cooled in the furnace. The results obtained on the joints that were made from 3-in. plates are shown in Fig. 10. Stress relieving increased the flux density on all of the specimens and eliminated the irregularities in the curves except that obtained on the tee fillet welds. The hump obtained on the latter specimens is probably caused by the separation of the plates at the root of the joint. The maximum flux density at the center hole, using 400 amp. and 6 in. spacing, increased an average of 74 and 100% for the specimens made from the 1 1/8- and 3-in. thick plates, respectively. There was some tendency toward a greater increase in flux in the joints having the largest mass of weld metal, such as the filleted tee and corner specimens, but this was not definite. Holes were also drilled in one of the 1 1/8-in. plates of the corner joint 3 in. from the plate

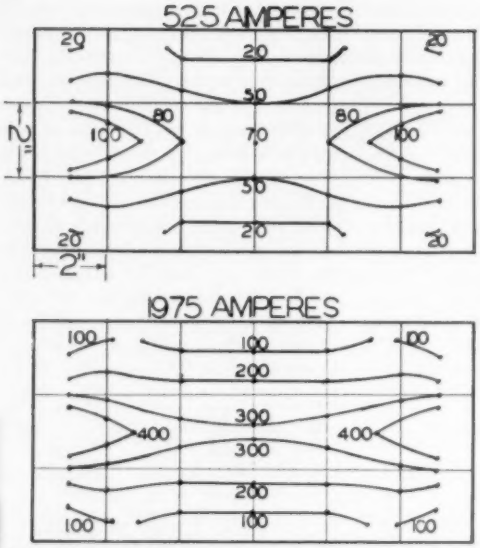


Fig. 12 Equiflux lines plotted from the maximum flux density readings obtained at various locations of one end of a block 6 × 12 × 3 in.

Electrodes were located at mid-thickness point and top end of block where measurements were taken

edge and checked in the as-welded condition and after stress relieving at 1175° F. for 4 hr. The maximum flux density at the center hole increased approximately 18% as a result of stress relieving. Figure 11 shows the range of maximum flux densities obtained on the weld specimens in the as-welded and stress-relieved conditions.

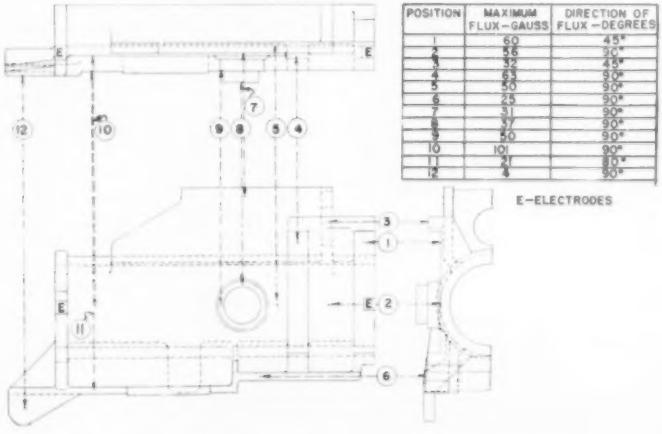
Equiflux Lines on Large Block

The variation in flux was studied on a surface of a carbon-steel block, 6 in. thick by 12 in. long by 3 in. wide. Thirty-six holes, 0.105 in. diameter by 3 in. deep, were drilled at various locations on a 6- x 12-in. surface. The block was then magnetized using currents varying from 225 to 1975 amp. with electrode connections midway of the thickness and at the ends of the face where measurements were taken. Flux-depth readings were taken in all of these holes. The maximum flux occurred at 0.04 to 0.10 in., corrected, below the surface at all locations. Equiflux lines were plotted from the maximum flux densities obtained at two of the currents and are shown in Figure 12. The flux density at the center of the block was three to four times higher than that obtained near the edges, but less than that near the ends where the electrodes were connected.

Irregularly Shaped Casting

The flux density of an irregularly shaped carbon-steel casting, having over-all dimensions of 40 x 22 x $1^1/_2$ in., was studied by drilling holes, 0.105 in. diameter by $^1/_2$ in. deep, at 12 different locations throughout the casting. The casting was clamped at each end and magnetized with 1925 amp. Readings were taken at various depths in each hole. A sketch of the casting, location of the holes and electrodes and the results obtained are given in Fig. 13. The maximum flux readings varied between 4 and 101 gauss and occurred $^3/_{16}$ to $^1/_4$ in. below the surface or at 0.04 to 0.10 in. corrected depth. Low readings would be expected at position No. 12 and high at No. 10, but No. 2 would be expected to be greater than one-half of No. 10.

It is evident from these results that the shape of the piece, mass, location of the electrodes and numerous other variables have an appreciable effect on the flux distribution which cannot be predicted accurately without taking such readings. If all areas on this casting are to be examined for subsurface defects, the low density areas would have to be magnetized in a different manner. This means that all areas which showed readings of possibly less than 40 gauss would have to be remagnetized, although more information is needed on the relation between the amount of flux and the size, shape and depth of defect.



POSITION	MAXIMUM FLUX—GAUSS	DIRECTION OF FLUX—DEGREES
1	60	45°
2	56	90°
3	92	45°
4	63	90°
5	50	90°
6	25	90°
7	31	90°
8	47	90°
9	50	90°
10	101	90°
11	4	85°
12	4	90°

E—ELECTRODES

Fig. 13 Flux density and orientation of the field values obtained on an irregularly shaped casting which had been magnetized with 1925 amp.

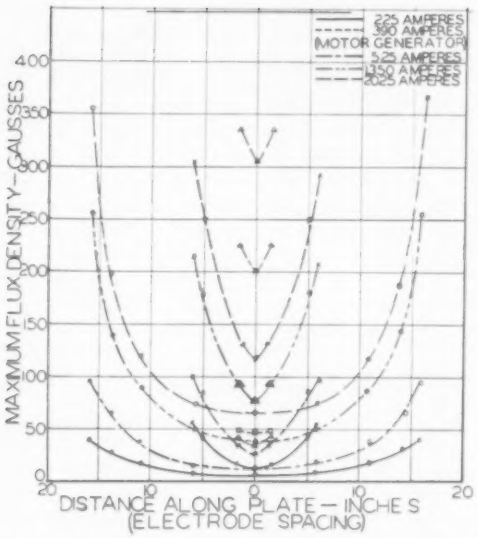


Fig. 14 Effect of electrode spacing on the maximum flux density of a 3-in. thick plate

Electrode connections were made on a 3- x 36-in. face and readings at spacings of 33, 13½ and 6 in. were obtained. The results obtained with the motor-generator, using 6-in. electrode spacing, is given for comparison

EFFECT OF ELECTRODE SPACING

Electrode spacing was studied on a round bar and a large plate. The round bar, 2 in. diameter by 60 in. long, was cut in three lengths—6, 12 and 37 in. Three holes, each 0.105 in. diameter by 1 in. deep, were drilled 1½ in. from each end and at midpoint for flux determinations, while the electrodes were connected at the center of each end. The 3 in. thick plate was cut 36 in. long by 24 in. wide so electrode spacings up to 36 in. could be studied, and the 24 in. was believed to represent a plate of indefinite width. Electrode spacings were studied on a 3- x 36-in. face by drilling holes, 0.105 in. diameter by 1 in. deep, at various locations along the center line of the plate and placing the electrodes 6, 13½ and 33 in. apart with respect to the center hole.

The magnetic fields were produced in the rounds and plate by applying currents approximately 200, 500, 1300 and 2000 amp. from the K.Q. 4.5 Unit and 390 amp. from a motor-generator unit. The results are shown in Figs. 14 and 15. The maximum flux density along the plate varied as much as 600% when 2025 amp. and 33 in. spacing was used with high field concentration at the ends. The 2-in. diameter bars showed variations of only 5% along their length, using 200 to 2025 amp. and with 6- to 37-in. electrode spacings. The maximum flux densities in the rounds at a given current was unaffected by variations in electrode spacing, but in the plate a 6-in. spacing increased the flux density considerably over that produced by the 13½- and 33-in. electrode spacings at all currents.

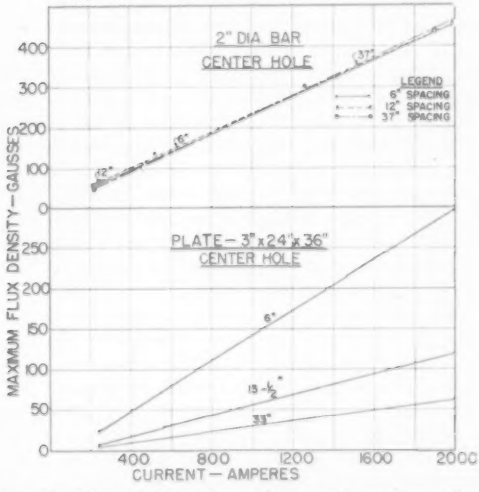


Fig. 15 Effect of electrode spacing on the maximum flux density of a 2-in. diameter round and a 3-in. thick plate

PRACTICAL APPLICATION OF THE METHOD

The relation between two methods of magnetic inspection was studied on a low-carbon steel tube, 7 in. outside diameter, ¾ in. wall and 6 in. long. A hole was drilled through the wall 3 in. from one end and then the tube was magnetized with 400 amp. from a motor-generator set by (*a*) using prods at ends of the tube and (*b*) inserting a 1-in. diameter copper bar through the

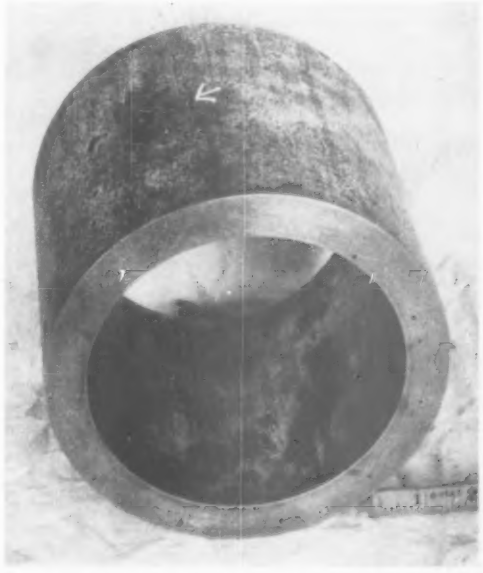


Fig. 16 Tube section used for taking flux density measurements and depth of defect determinations

center of the tube. Flux readings were taken at various depths through the wall. Holes 0.07 in. diameter were drilled in the wall of the tube at various depths below the surface. The minimum current required to obtain a definite pattern for each hole was then determined using each method. The tube is shown in Fig. 16, and the flux-depth curves and minimum detection curves are shown in Fig. 17. The indirect bar method gave only about 40% of the maximum flux density obtained by the prod method, but at depths about half way through the wall the curves cross and the indirect method gives higher readings. The maximum depth of hole located by each of the two methods with 400 amp. showed that the same relationship holds, i.e., the deepest hole located by the bar method was 0.10 in. below the surface, whereas the prod method located the hole 0.25 in. below the surface. At these depths the flux densities were 37 and 64 gausses for the bar and prod method, respectively.

UNIFORMITY OF THE GAUSSMETERS

Four meters, one 0–100, two 0–500 and one 0–1000 gausses, were examined to determine their uniformity under the same conditions of test. Three meters were relatively new, while one had been in use for over 2 yr. They were inserted in the center hole of a stress-relieved steel bar, 2 in. diameter and 12 in. long, using four currents ranging from 225 to 1950 amp. The depth of each meter was accurately controlled by means of a depth gage. Accuracies of 1, 2 and 3 gausses were obtained on the 100, 500 and 1000 meters, respectively. The curves obtained on these meters are given in Fig. 18. Practically every meter gave readings within 5% of each other at all currents and depths.

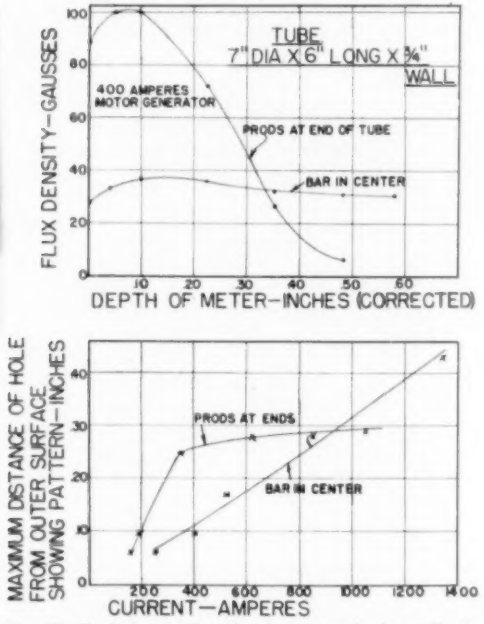


Fig. 17 Variation in flux density through the wall of a tube and the current required to locate 0.07-in. diameter holes in wall of tube which were magnetized by two methods

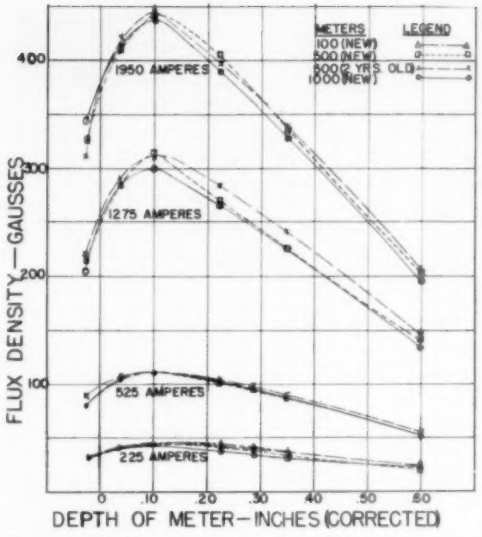


Fig. 18 Variation between meters of different ranges and ages

Results were obtained on the center hole of a round bar, 2 in. diameter by 12 in. long, with electrodes connected at the center of each end

DISCUSSION OF RESULTS

It is realized that the gaussmeter measures only the flux in the hole and not that in the metal. However, the results obtained indicate that there is a relationship between the flux passing through the hole and that in the metal. The constant drop in flux from near the surface of all sizes of rounds to almost zero at the center is in accordance with theory; the higher flux density on the 3-in. thick plate than on the $1^1/_8$-in. plate of the butt-welded specimens is in accordance with the findings obtained by Hastings[6] on welded specimens containing artificial defects, while the 75 to 100% increase in the flux density after stress relieving of the welded specimens is in accordance with the results obtained in practice and on welded test blocks containing artificial defects.

The results which are not in accordance with theory are: (1) The lower flux values obtained at the surface than at the peak point which was usually 0.04 to 0.10 in. corrected depth below the surface. (2) The slightly lower flux values on the inner wall than the outer wall of the 7-in. O.D. tube when magnetized by the bar method. The former may be due to the size of the magnet in the gaussmeter or the flux leakage across the top of the hole. The latter, which needs

further investigation, may be caused by the thinness of the tube wall and the relatively large inside diameter of the tube with respect to the 1-in. diameter copper bar which carried the current.

The location, in weldments after stress relieving at 1175° F., of new defects which were not found in the as-welded condition has been known for some time. This was checked further on welded specimens containing artificial defects and it was found that defects can be located at approximately twice the depth as were seen in the as-welded condition. The flux density values obtained on the welded specimens described in this investigation show that the flux density is considerably higher at all depths up to 1 or 2 in. below the surface after stress relieving than was found in the as-welded condition. This is believed to be due to the removal of stresses in the welds and to a lesser degree the release of hydrogen gas. Henry and Claussen[7] state that welded structures contain shrinkage stresses of all magnitudes up to the yield strength. The removal of these stresses by stress relieving is primarily due to recovery (200 to 1000° F.) and relaxation (above 1000° F.). Stanley[8] states that certain magnitudes of elastic strain can be instrumental in changing the permeability of iron, and gases such as hydrogen, oxygen and nitrogen, when trapped in lattice, are harmful to magnetic properties, although the latter two gases are believed more harmful than the first.

USES AND LIMITATIONS

These gaussmeters can be used to study flux density in magnetic particle testing in determining:

1. Effect of various methods of magnetization.
2. Effect of heat treating on alloy steels and the amount of residual magnetization.
3. Use in specifications—specify the range of allowable flux densities or minimum flux density at a particular location and depth.
4. Amount of flux in irregularly shaped steels and the orientation of the flux.
5. Effect of different variables, such as amount of current, surge, stress relief in welds, electrode spacing, etc.
6. Effect of different kinds of magnetizing equipment.
7. Relation between steels of similar composition.

They have the following limitations:

1. They cannot be used to measure fields resulting from alternating current.
2. They cannot be used satisfactorily on steels less than $^1/_2$ in. thick.
3. They cannot be used on steels whose temperature is above 50° C.
4. Preferably, they should be used with the rods of the meter in the vertical position.

CONCLUSIONS

1. Gaussmeters described herein gave results which were consistent with theory or experience and, therefore, are satisfactory instruments for determining the flux density in steels which are magnetized under controlled conditions. Those having the 0–500 and 0–1000 ranges can be read within an accuracy of 2 to 3 gausses and are probably preferable to the other ranges.

2. The maximum flux density occurred at the highest amperage used. It was found to be 650 gausses for the $^3/_4$-in. diameter round and only 320 gausses for the 6-in. thick plate.

3. Increase in diameter of the rounds from $^3/_4$ to $7^1/_2$ in. decreased the amount of flux, while increase in the thickness of plates from $^1/_2$ to 6 in. resulted in an increase of flux when electrode connections were made at the center of each end of the rounds and one end of the plates. The flux dropped to zero on the rounds at depths equivalent to the radius of the bar and then reversed itself; on the plates which were 12 x 12 in. the flux dropped to almost zero, but did not reverse itself at depths up to 5 in.

4. The rate of decrease of flux density with increase in depth in various shapes and sizes of steels is not uniform and varies with respect to the amount of current, size and shape of piece, electrode location and spacing and many other variables, and cannot be predicted accurately except for a few simple shapes.

5. The length of electrode spacing between 6 and 37 in. has no effect on the flux density of 2-in. diameter round bars, but has considerable effect on a plate 3 in. thick by 36 in. long by 24 in. wide when current is passed through one end. At 2000 amp. the flux at the center hole of the plate dropped from 305 gausses to 65 gausses as the electrode spacing increased from 6 to 33 in. The prod method, using approximately 400 amp. and 6-in. electrode spacing, showed slightly higher flux at the center hole of the plate than was obtained with 1350 amp. and 33-in. electrode spacing.

6. The maximum flux density of the weld specimens made with the 3-in. plate was usually higher than those made from the $1^1/_8$-in. plate for all currents in both the as-welded and stress-relieved conditions, although there is some overlapping.

7. Stress relieving the welded specimens at 1175° F. increased the flux density from 75 to 100% over that obtained in the as-welded condition. In general, the specimens having the larger amount of weld metal, such as the tee fillet and corner joint, showed greater increases than the tee double bevel and butt joints.

Stress relieving the $1^1/_8$-in. plate of the welded corner joint increased the flux density values 18% over that obtained on the as-rolled plate. The increase in flux density of the welded specimens is believed due to a release of stress and possibly hydrogen gas; in the plate it is due to stress only.

8. Flux density-depth values and the results obtained on artificial defects in the $^3/_4$-in. wall of a tube shows that there is a definite relationship between flux density values obtained with the gaussmeter and depth of hole.

ACKNOWLEDGMENTS

The author gratefully acknowledges the help received from various members of the Welding Section of the Laboratory. The assistance of W. E. McKenzie, Principal Welding Engineer, for his encouragement, suggestions and criticisms, and T. A. Mowatt for his comments was most helpful, while K. Davis assisted in making all of the tests.

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Discussion by C. E. Betz

Mr. Hamill's paper is one of the most interesting and thought-provoking studies on the subject of magnetic particle inspection that has been presented in a long period of time, and he is to be congratulated on having done a highly useful job, which has obviously required a tremendous amount of work.

There is little authentic or dependable information available on the subject of field distribution in large and irregular shaped objects, so that the present work, employing a new approach, is extremely timely and it is to be hoped will stimulate additional studies in this field.

Mr. Hamill states that the method might be considered "destructive" but this does not seriously limit it as a means for studying field distribution as a preliminary to setting up inspection standards on typical specimens, especially since on large castings and forgings repair of the drilled holes may be possible.

His application of the method to a large irregular shaped casting is a good example of how the technique he describes can be used to lay out a practical test procedure. Before deciding on a suitable flux density it would be necessary to know what field strength is required to show sought-for defects. It seems obvious that with adequate currents considerable areas of a casting will have a sufficiently strong field for satisfactory inspection, and the use of prods and local magnetization at the points of low flux density, when known, would enable the operator to make a complete test with a minimum number of operations.

Some of the test results pose questions which they do not answer and suggest lines for future work.

For instance there is the observation that for the plate specimens there is an increase of flux density at the same current level, with increase in plate thickness, whereas the contrary is true for the bars as diameters increase. The latter is to be expected while the former seems, at first thought, surprising.

In the case of the bars the current is applied at the center of the ends and symmetrical fields are produced. In the case of the plates the electrodes are applied near one face, and current and therefore field distribution is not symmetrical. The variations in flux densitie in plates of different thicknesses, within the depths explored, are unquestionably due to differences in current distribution as thickness increases. The area of electrode contact in proportion to plate thickness may also be a factor in the way the current distributes itself within the metal.

The observation of the occurrence of "peak points" of flux concentration at some distance below the surface is very interesting. The author's explanation that this is due to the physical size of the instrument and to flux leakage across the top of the hole is undoubtedly correct up to a point, and on the rounds there seems little question that the maximum flux density actually *is* at the surface.

But in the case of plates, this explanation seems scarcely adequate to account for a flux density peak as deep as 0.80 in. which was observed at low currents in thick plate. And, incidentally, why should current *value* affect flux *distribution* in the same specimen?

The whole subject of field distribution when using prods on heavy plate is a fascinating one and provokes endless discussion. The data plotted in Fig. 14 certainly points up the importance of close prod spacing to get high flux densities between the prods. But what happens deep in the plate? In Fig. 9 no evidence of a reversal in flux direction is reported, although measurements seem to have been carried practially through the plate thickness. It would seem flux direction must reverse somewhere in the section.

Tests made in our laboratories indicate that even with electrodes applied at one face, 12 in. apart on 3-in. thick plate, a reversal of field direction occurs at approximately the center of thickness midway between the contacts.

The presentation of equiflux lines bears on this problem also. It would be highly interesting to see such a plot made for three dimensions instead of in just one plane, though this would require a very large amount of work.

In the study of electrode spacing on rounds, it would also be interesting to see the effect of the spacings indi-

C. E. Betz is Executive Vice-President, Magnaflux Corp., Chicago 31, Illinois.

cated when made on the surface of one long bar and not on bars cut to length with electrodes centrally applied on the ends.

The effect of stress relieving on the detection of subsurface defects in welds has been observed in practice. Increase of permeability and therefore of flux density at a given current level is probably the principal factor although increase of uniformity of field distribution will certainly also make for greater depth sensitivity.

Nonrelevant indications at the edge of the heat-affected zone in welds have been thought to be due to differences in hardness causing differences in permeability. Would not stress-relieving at 1175° F. also tend to draw these harder areas, and thereby increase the magnetic uniformity of the material?

As stated at the outset Mr. Hamill's paper provokes thought, and discussion could go on and on. The data will be studied in detail in our laboratories, and we will certainly be interested in pursuing some of the lines of investigation which the paper suggests.

Discussion by Carlton H. Hastings

The writer is particularly interested in Mr. Hamill's paper for two reasons:

1. Information regarding the detectability of flaws under certain conditions, and described by myself in Reference 6 of this paper, have been checked by a nicer and more positive method than previously employed.

2. The existence of a new device and its application to magnetic particle testing have been indicated. My experiences for the past six months with the gauss meters described by the author have verified their utility as a laboratory tool for such studies as Mr. Hamill has conducted. It has not been easy to visualize, however, how they might be used as tools in the hands of the inspector. It does not seem practical to expect a shop to drill holes in its products, as is necessary to make measurements with these meters, and then to chip or otherwise enlarge the holes to the point where they can be repaired by welding. At least, this does not seem practical if it can be avoided. I believe it can be avoided.

During the War, the desire was expressed on the part of some individuals concerned with magnetic particle testing for a device which could be used to check the level of magnetization in pieces to be tested. It was found difficult to obtain uniformity of test results from one inspector to another and from one shop to another, because of the lack of such a device. The situation gave rise to the development of several devices for the evaluation of magnetic flux. (See references 2 and 4 of Mr. Hamill's paper.) One of these, known as the General Electric Magnetic Field Gage, became available commercially. It was found by users of the device that, while it was suitable for the evaluation of flux at the surface of a magnetized part, and data obtained could be related to surface flaw detectability, it did not correlate well with the detection of subsurface flaws which could be detected with the magnetic particle method. This lack of correlation was probably due to the difficulty of and consequent error in estimating the relation between subsurface flux in the piece, which determines the detectability of a subsurface flaw, and the surface flux measured by the field gage. The error is particularly apparent in the case of pieces of complex shape and varying thickness.

It would seem practical to utilize the gauss meter employed in Mr. Hamill's work, not as a tool in the hands of the inspector as suggested, but as a laboratory tool by means of which the test engineer can obtain information regarding the correct relationship between surface and subsurface flux at desired depths in parts of complex shape or size. The specifications on magnetic particle test procedure could then require surface flux readings during production shop inspection operations with assurance that the readings are significant. Under these conditions, the Magnetic Field Gage could be used more reliably, and would not require the drilling of holes in production items.

I believe that Mr. Hamill's work, together with the foregoing suggested method for practical application, could pave the way for greater uniformity of magnetic particle test results through standardization of test procedure.

Carlton H. Hastings, Physicist, Watertown Arsenal Laboratory, Watertown 72, Mass.

The statements or opinions in this discussion are those of the author, and do not necessarily represent the views of the Ordnance Department.

Author's Reply

The primary use of the gaussmeters appears to be in a study by the engineer of the variables encountered in magnetic particle inspection. From the results obtained, it is possible to specify certain procedures to be used. If it is desired to use a different procedure from the one specified, the gaussmeter should be used in order to make sure that the required flux density is obtained. It should only be used by an inspector under very special conditions and certainly not for the purpose of drilling holes wherever he desires to know the amount of flux. It may be possible to correlate the values obtained with the gaussmeter to those obtained with the G. E. Magna-Gage, although my experience with the latter shows that their application is limited in regard to shape of material, condition of the surface, range of flux densities and difficulty of calibration.

Flame Cutting

Installation and maintenance of flame cutting installations and procedures which contribute to economical operation

by James T. Lewis, Jr.

INTRODUCTION

FLAME cutting has become such a well standardized and generally accepted process in the metal fabricating industry that a discussion of fundamentals will serve no purpose at this time. A number of manufacturers have developed equipment that is generally reliable, readily maintained and sufficiently standardized so that operator training presents no real problem.

The purpose of this discussion is to outline the typical application of the equipment available, describe its installation and maintenance and point out a few procedures which contribute to economical operation. A description of some special equipment we have built is also included to illustrate how some of the standard equipment can be modified to suit specific requirements of accuracy, speed and shape when sufficient production warrants the expense. In many respects, flame cutting might be considered as a type of rough machining, and many of the principles of machine shop operation can be applied.

The first step in laying out a flame-cutting department is the calculation or estimation of the work load. The selection of equipment must be made on the basis of the amount of cutting to be done. If a limited amount of nonrepetitive work will be a typical plant conditions, a small and inexpensive hand-tracing machine will be perfectly practical. On the other hand, if the flame cutting requirements are a major factor in production operations the department will probably require several template-tracing machines of various sizes, together with whatever special equipment is developed for quantity production. Manufacturers engineering representatives are probably the best source of information as to the proper type, size and capacity of cutting machine to accomplish the work concerned.

James T. Lewis, Jr., is with the Lewis Welding & Engrg. Co., Bedford, Ohio.

Presented at the Thirtieth Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

OXYGEN SUPPLY

Also using the work load as the basis of computation, the source of oxygen and fuel gas must be determined. If the operation is on a small scale the use of gas supplied in cylinders is probably the simplest and most economical. There is no appreciable installation cost involved and there is the convenience of portability. If, however, the oxygen consumption exceeds 1000 cu. ft. per day, a permanent piping system becomes almost a necessity. Three basic methods of installation are available.

The first method involves the construction of a loading dock on which is located a pipe manifold to which can be attached 10 to 20 cylinders in two groups. Half of the connected cylinders will be open and supplying oxygen and the others will serve as a reserve supply, automatically cutting in when the first group is exhausted. At the time of cutting in the second group, the empty cylinders can be replaced with charged ones, so that the supply lines can always be under pressure and the work can continue uninterrupted during the changeovers (see Fig. 1).

A variation of this installation is the use of large capacity cylinders mounted on trailers. Instead of loading individual cylinders, the entire trailer load is connected as a unit and thus serves as a reservoir of several thousand feet. When the trailer load is exhausted the trailer is withdrawn and a new one connected in its place. The down time is negligible and the operations can continue virtually uninterrupted.

The third type of installation utilizes a bank of large cylinders having a capacity of many thousands of cubic feet. These cylinders are permanently connected to the supply lines running through the shop, and suitable regulating valves maintain a constant pressure at all of the outlets. Delivery of the oxygen is usually made in the liquid state in specially constructed tank trucks. Delivery can be made at any time and without interference with the shop production schedules, and because of the large quantities

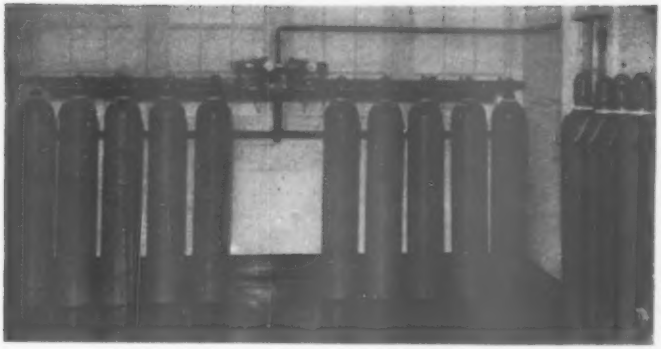


Fig. 1 Portable cylinder manifold installation

involved the delivered price per cubic foot is a minimum (see Fig. 2).

Besides the low cost of the oxygen itself and the inherent convenience of the last type of installation, the fact that the reservoir need never be emptied presents additional savings. Whenever portable cylinders are used there is always some residual gas which cannot be recovered because of the working pressures. This amount is small per cylinder, but is an appreciable cost item over a period of time.

If the consumption level is high enough, the possibility of manufacturing oxygen on the premises should be investigated. Several units are now available which operate on the principle of fractional distillation of liquefied air. The costs of operation are not excessive and the raw material is free. If the volume warrants the initial investment and the labor cost of operating personnel, the net cost of oxygen produced will be appreciably below that at which it can be purchased and handled by any of the three methods just discussed. High purity oxygen is vital to economical and reliable flame-cutting practice, but it can be made successfully in the small plant. Again, actual costs involved are the determinant. In our own operation, based on using 200,000 cu. ft. per month, we decided against manufacture.

FUEL GAS SUPPLY

The same considerations apply to the method of purchase and handling of fuel gas. If the size of the installation warrants the initial investment, the permanently piped supply will prove more convenient, safer and more economical than the use of individual cylinders.

The selection of the most suitable gas to use is a decision which calls for careful study. Natural gas, dissolved acetylene and several mixed fuel gases are available. All of them work but, in our opinion, for all-round use in cutting, welding and local heating for forming and straightening, acetylene generated on the premises gives the lowest cost result. The high temperature of combustion of acetylene with the resultant faster preheat reduces cutting time and has proved its worth in subordinate operations such as descaling, shrinking and flame hardening which are all associated with the flame-cutting department.

CUTTING MACHINES

The automatic flame-cutting process can be divided into three major shape groups: straight lines, circles, and shapes other than the first two. The selection of the type of shape-cutting machine is largely determined by the kinds of shapes to be produced. Any one of the standard types of template tracing cutting machines can produce virtually any shape, but if sufficient volume of work is contemplated, special equipment will be found to have improved performance from the standpoint of speed of handling and accuracy in the finished piece.

For example, a circular template will produce circular pieces, but it is significant to note that a circular bevel cannot be cut from a template because of the fixed angle of the torch. Therefore, if a part is to be beveled, two complete setups are required with the accompanying loss of time. If, on the other hand, a machine is built similar to the one shown in Figure 3, whereon the piece is rotated, square edge cuts or bevel cuts at any desired angle can be produced with equal facility. Variable speed is provided to give a range of from one-third to two rpm. on the table, which when converted to linear speeds at the cutting line, permit the cutting of a wide range of diameters and plate thickness.

As a second example, straight lines can be cut with any standard machine, but we find that a "stripping"

Fig. 2 Fixed cylinder storage bank

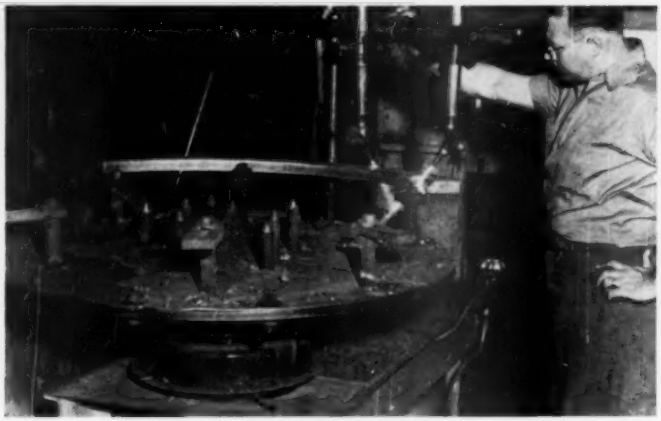


Fig. 3 Circular cutting machine

operation can best be performed with a machine built for that specific purpose. Figure 4 shows the general arrangement of such a piece of equipment. Eight standard torch assemblies are mounted on a continuous rack so that any point on the 120-in. span can be covered. In this way as many as eight simultaneous cuts can be made and strips of infinitely various widths can be cut from all thicknesses of plates and in lengths up to 30 ft. By having both edges of the strips cut at the same time and using a water spray to follow closely behind the cutting, we can produce long narrow plates which are within $^1/_{16}$-in. limits of width and which have a camber which is a fraction of that experienced with the usual mill-rolling practice.

This particular machine is designed like the bridge of a traveling crane, with driving wheels on both runway rails. The wheels in one "end truck" have no float and the others have sufficient float to compensate for track irregularity. It is important to note that the truth or accuracy of the straight cut is entirely dependent on the installation of the rails. A heavy foundation to absorb extraneous vibrations and a first-class job of millwrighting are the only guarantees of accurate finished pieces.

A constant-speed motor drive is provided and infinitely variable speeds from 0 to 30 in. per minute are produced by mechanical means. With this arrangement, constantly maintained cutting speeds are assured. Flexible connections for oxygen, fuel gas and water are brought to one location so that the operator has all of his controls at one point for greatest ease of handling. Each torch can be raised and lowered independently and can be set at any desired angle. Each torch has its own water nozzle for use when quenching is required. Figure 4 shows a close-up view of the torch assemblies, and Fig. 5 shows the general arrangement of the machine.

TEMPLATE TRACING MACHINES

Each manufacturer has particular "features" about his cutting machine which makes it more desirable than the next one. Machines are available for repetitive production which follow formed wire templates, milled groove templates, which by the use of photo-electric devices and electronic controls will follow the edge of a "silhouette" drawing, and still others with magnetic tracing attachments which follow the edge of a steel plate template. Our own choice of machine has been one which will operate on either the formed wire or steel plate template and which can be changed from one type of template to the other in a matter of minutes.

There are several design features which we feel are of particular importance, and they are enumerated here:

1. Inherently rigid construction. Avoid the sacrifice of stability for light weight
2. Readily accessible and replaceable drive unit to permit quick repair and maintenance.
3. Multiple torch holder to permit two-, three- and four-at-a-time simultaneous cuts.
4. Controls grouped together and at the cutting head of the machine for fast manipulation and easy adjustment.
5. Quick acting valves for control of gas.

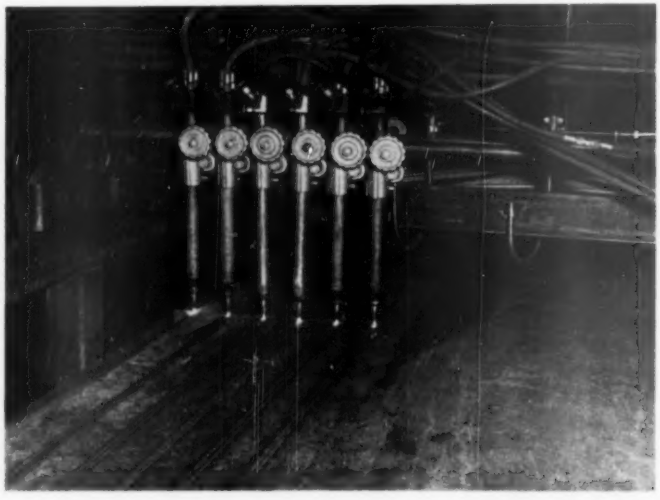


Fig. 4 Close-up of stripping machine torch assembly

Fig. 5 General view of stripping machine

6. Direct-reading cutting speed gages.
7. Rigid track assembly, firmly mounted on heavy foundations to eliminate or minimize the vibration.
8. Adequate track cleaners to wipe off dirt and scale and reduce wheel and track wear.
9. Runways, template table and work support table made as long as possible so that the maximum stock size of plates can be set up and finished without rehandling.

STACK CUTTING

Much has been said and written about the advantage of stack cutting—the process of cutting a number of pieces in a stack at one time. Our own experience has lead us to abandon this type of operation in favor of multiple torch cutting whenever high production of identical pieces is required.

In the first place, much time is consumed in the preparation of the stack of raw material. The plates or sheets must be in very close contact and hence must be more than usually flat. They must be pressed tightly together and secured by welding or clamping. Gaps between adjacent plates will usually interrupt the flame cut, with the resultant probable spoilage of some pieces and the necessity for reassembly of the stack for a new start.

In the second place, it is very difficult to maintain constant dimensions in the finished pieces from the top to the bottom of the stack. If close dimensional tolerances and a high degree of accuracy are required, we have found that stack cutting produces far too many rejects.

MAINTENANCE OF EQUIPMENT

Cutting equipment is expensive. It must have reasonable care if good results are to be expected. The constant presence of the highly abrasive slag is a source of wear, and hence inaccuracy. Tracks, gearing, guides, templates, tips and, in fact, every part of the apparatus must be kept as clean as possible, and should be made an important item of shop regulation.

One method of assuring adequate care of the equipment is to assign a machine to an operator and give him full responsibility. He should be given a complete set of cutting tips for his own use, a cover to protect the machine when it is not in use, and at least two specified time periods each day when he is to clean his equipment and examine it for signs of wear or maladjustment. Actual repair of the machine or repair of templates is referred to qualified maintenance personnel, but we have found that the assignment of personal responsibility to the operator has made a great contribution to the quality of the work and to the reduction of down-time and repair bills.

ACCURACY OF FINISHED PIECES

Although the shape-cutting machine is not an accurate tool, in the same sense that we consider a fine machine tool, it can be made to produce pieces to reasonably close limits. Assuming the machine itself to be in the first class condition there are many other factors which must be accounted for if the best results are to be obtained.

The cutting tips must be clean and true. Dirty or worn tips are probably the one greatest source of poor workmanship. The actual cutting is done, of course, with a fine, high velocity stream of oxygen. Any wear in the orifice, or particle of slag adhering which might deflect or change the shape of the stream, will interfere with the cut and spoil the results.

All the cutting pressures, speeds and sizes of nozzles are tabulated by the equipment manufacturers. Any material variation from these published values should not be permitted because no actual advantage can result. It is a frequent tendency of operators to use excessive preheat flame and excessive cutting oxygen pressure in an effort to avoid interruptions in the cut. Excessive preheat produces a poor edge to the cut, and excessive pressure wastes gas. Proper operator training and adequate supervision are the only methods of combatting the problem.

Recalling that the thermal coefficient of linear expansion of steel is approximately 0.000006, an expansion and contraction problem is immediately apparent. For example, if a steel plate 100 in. long is raised 100° F. in the course of a flame cut, the length of the piece will be increased about $^1/_{16}$ in. The final effect would be the production of piece $^1/_{16}$ in. too short after it has cooled.

Another source of error is the width of the kerf itself. Still another and very frequent cause of inaccurate finished pieces is the failure to maintain square edges. The over-all dimensions of the finished work will be materially determined by the degree to which all of these factors are controlled.

The first point of attack is in the construction of the

templates. Width of kerf and shrinkage are anticipated as much as possible, but a careful check of the first piece cut is the only sure method of control which, we have found. After the first piece is cut out, any necessary alterations are made to the template and another piece cut and checked out in the same manner. Then, if all dimensions are satisfactory, the production run is made.

The same rules apply to old templates taken from storage. The wire type templates are fragile and require careful handling and the only sure method of getting satisfactory results is to inspect the first pieces cut each time, making template repairs as indicated.

FLAME CUTTING VS. MECHANICAL CUTTING

The costs of flame cutting can be calculated to reasonably close limits. They will vary, of course, from one shop to another because material handling methods vary and handling is such a large factor in the total cost. The actual cutting time per unit length of cut, however, can be well standardized.

Now the cost is high and understandably so. Oxygen costs between one half cent and one cent per cubic foot; acetylene costs between one cent and two and one-half cents, both figures being determined by quantities concerned. To simplify cost accounting procedures we use average consumption figures and for each man-hour of flame cutting department time we set up an overhead charge of $1.00. This figure has varied within 10% limits over a twelve-month period.

A dollar an hour must then be added directly to wage costs, in *addition* to general shop overhead. Capitalizing this charge on a ten-year basis will more than pay for shears, nibblers or band-saws, so the decision as to whether or not flame cutting is the most economical method of production depends on other factors than the cost of the gases consumed.

If multiple cutting is possible in the production of a given piece, and it frequently is, the total cost per piece, including wages, general expense and gas charges, will be materially reduced. If there are interior cut-outs, the ability to complete the pattern in one setup will favor the flame-cutting procedure. Size of the finished piece, both in thickness and extent, is an important consideration. Pieces of large area are too awkward to handle in nibblers and band-saws. Pieces more than 1 in. in thickness cannot be sheared to close enough dimensions for most welding fabrication.

We have found that a combination of processes is frequently indicated. For example, let us consider a rectangular plate of $^1/_2$ in. thickness, about 5 ft. square. The design calls for one rounded corner with an 8 in. radius, and six 5-in. diameter holes cut in the interior. We would shear the rectangle to size and flame cut the one rounded corner and the interior holes. If the piece were flame cut all around, there would be a total of approximately 28 linear feet of torch cut. By shearing the outside edges, a much faster method, only 10 ft. of torch cut is involved. If there are a number of pieces to be cut, suitable stops could be set up on the work table and a template so located that the operator need measure for the first piece only, thus saving much on production time.

Whereas this is a typical shop problem, no hard and fast rules are possible. Each piece must be studied on its own merits. So much time is consumed in handling the material between operations, setting up prior to cutting, and handling the pieces after the cut is finished, that some time-study is necessary in making the decisions as to what method to follow. Even the most informal study on the part of the department foreman will prove valuable.

COSTS OF FLAME CUTTING

Each company has its own methods of allocating costs and distributing labor charges. Our own experience, however, probably represents a fairly average situation. For single torch work we find that the total production time represents three times the theoretical cutting time.

Again taking an example, if a particular shop operation requires 1000 ft. of cut, with a theoretical cutting speed of 12 in. per minute, we would allow a total time of 3 × 1000 min., or 50 man-hours. This figure, on an average, has proved reliable over a period of many years.

CONCLUSION

In conclusion we wish to emphasize that flame cutting is an important and at the same time an expensive part of the metal working production field. In our own plant, which is devoted entirely to welded steel fabrication, the flame-cutting department requires 10% of the total direct labor. Material handling in the department is a problem in itself and one worth a great deal of study. Equipment selection, shop layout, gas supply and method supervision can also pay big dividends in cost savings and are well worth extensive study on the part of the shop management.

Welding in the Meat Packing Industry

Inert-gas-shielded arc welding of stainless steel of 20 gage and heavier provides strong, sanitary products used in the meat packing industry

by Charles Bonifield

THE handling of meats by the packers imposes severe demands on equipment. Not only must it be of rugged construction to withstand rough treatment and severe abrasion, but it must be completely sanitary. No pockets or laps that might entrap particles and resist normal cleaning methods can be tolerated. The whole problem calls for simple, strong, smooth design incorporating the extensive use of stainless steel and welded joints that can be smoothed to mirror finish.

The transition from the use of galvanized iron and soldered joints to the unbroken surfaces of welded stainless steel posed many new problems from a manufacturing standpoint. Old concepts of forming, fastening and finishing were altered to bring out the best characteristics of new materials. A typical example was the early adoption of normal arc welding procedures. Arc welding provided smooth corner contours and unbroken surfaces for the user, but from a manufacturing standpoint, material and finishing costs were high. Our present answer is the extensive use of the inert-gas-shielded arc-welding technique.

This method of welding is unique and quite simple. An electric arc is established between a relatively nonconsumable electrode and the work (Fig. 1), thus providing an intense welding heat. Both the welding zone and the electrode are protected from atmospheric contamination by a blanket of absolutely inert gas—usually argon or helium. Most joints applicable to stainless steel welding can be handled in any position, and in material thicknesses from 20 gage and heavier. I understand even lighter material can be welded mechanically, but our work and this discussion is primarily concerned with hand welding. Filler material in the form of bare welding wire may be added or not as required. No flux is used, but the material must be free from oil or dirt.

The equipment, too, is quite simple. Figure 2 shows a typical setup exclusive of power supply. Welding current is conducted to the water-cooled fuse assembly, through a water-cooled cable to the torch and electrode.

Charles Bonfield is Vice-President of The Globe Co., Chicago, Ill.

Presented at the 30th Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

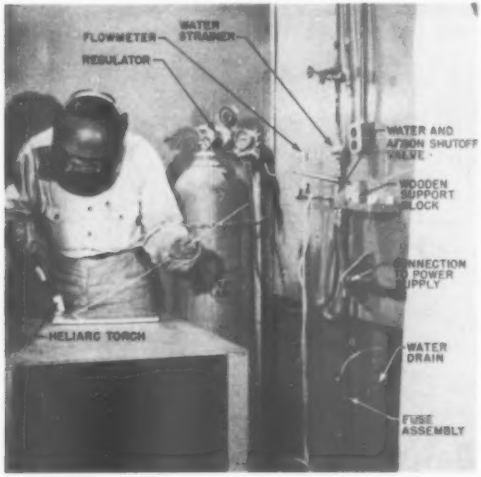


Fig. 1 Inert-gas-shielded arc welding with a "Heliarc" torch

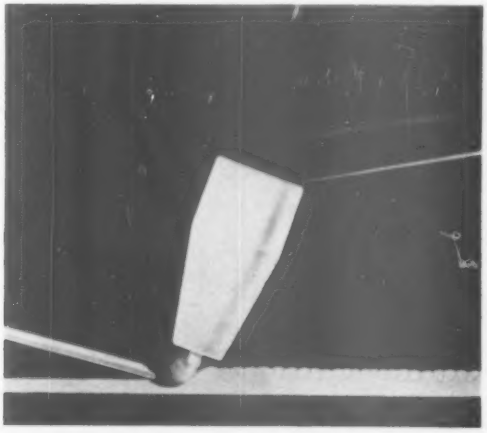


Fig. 2 Typical installations for "Heliarc" welding

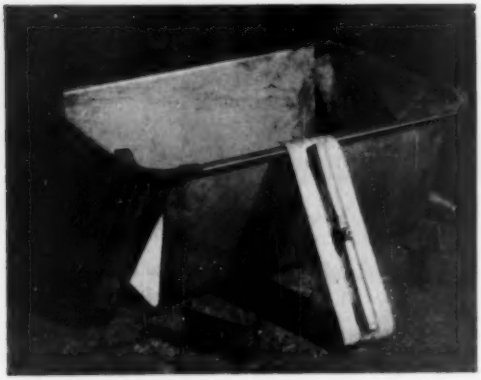


Fig. 3 Component parts of stainless steel truck

It is advisable to install a strainer in the cooling water supply as the torch head passages are necessarily small and can be plugged by rust particles. When a water supply is not available, the torch may be cooled by a small closed circulating water system.

Argon gas is supplied in high pressure cylinders. This pressure is reduced to about 30 psi. by the regulator, and the flow of gas is accurately controlled by the flowmeter. After completing a weld the operator shuts off both the water and argon by hanging his torch on the hook-shaped valve handle.

We use both alternating current transformers and direct current motor generator sets for inert-gas-shielded welding, but the d.-c. sets predominate and the a.-c. machines are mainly for the lighter gages of material. From my contacts with others using this welding process I judge this to be common practice, although the present tendency seems to be to use d.-c. straight polarity almost exclusively due to its greater penetrating power and higher heat concentration, which results in less distortion.

Fig. 4 The heads of the truck are made with rounded corners by welding in cupped pieces. Welds on the rounded corners are ground flush

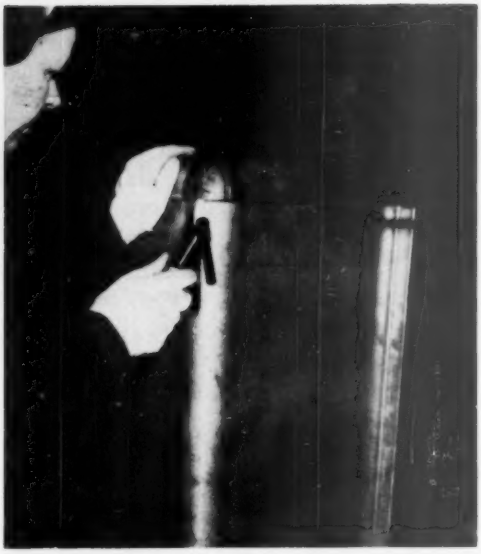


Fig. 5 Tack welding the head to the wrapper sheet. No rod is added

Most of the items made in the shop are processed in small lots or as individual pieces so it has not been economical to resort to either mechanized welding or extensive jigging. A typical example is shown in Fig. 3. Sixteen separate pieces are preformed and subsequently welded into the finished sanitary tub which will be used transporting sausage meats within the packing house. The material is 18–8 stainless steel Type 302 and most of the parts are 14-gage stock with 2-B finish. Practically all welding operations on this

Fig. 6 Welding the head to the wrapper sheet

Fig. 7 A quick pass with the "Heliarc" torch smooths the back side of the weld and reduces grinding and finishing

Fig. 8 Reinforcing corners are fillet welded to the truck body and flange

Fig. 9 Welding in and smoothing over the lap joints at the corners on the top side of the flange

Fig. 10 Fillet welding caster plate to 14-gage truck bottom

item utilize straight polarity d.-c. current, the amperage varying with the joint and thickness from 60 to 150 amp. Five liters per minute argon flow is sufficient for weld protection.

You will notice that some of the parts are subassemblies. Stamped, quarter round, corners are tacked in place to the head assembly (Fig. 4). Tack welds are made at intervals of about $1^1/_2$ in. and the joints are subsequently butt welded from the outside allowing 100% penetration. As no jigging is employed to protect the back of the joint from oxidation, it is somewhat rough and the operator smooths the back with a second pass of the torch. No filler metal is required, and a relatively light grinding operation smooths the inside to a sanitary finish. The ends are tack welded to the preformed wrapper sheet progressing across the bottom and then up each side. The tack welds are made at intervals of about 2-in. as shown in Fig. 5. Note that the fit-up is good considering the type of operation. Generally speaking, we have found that a little extra time spent on previous operations to secure tight fitting joints pays excellent dividends in ease of assembly, higher welding speeds, less (or no) rod required both for tacking and to fill the gap, less distortion, less grinding and a smoother final product.

Welding is done from the outside (Fig. 6) adding filler rod as required. The weld progresses at about 12 in. per minute. Filler material is $^1/_{16}$-in. diameter plain stainless rod of an analysis similar to the base metal or Type 347 stabilized. In order to minimize grinding, the operator smooths the underbead by making a second high-speed pass. This operation is shown in Fig. 7.

Top corners are clamped in position with "C" clamps, tacked, and fillet welded to the tub from the back (Fig 8). This operation requires rod addition to fill any gaps and for stiffening.

At this point (Fig. 9) the tub proper is almost complete. Note particularly the neatness of the welds and lack of distortion. Good fit-up, secure and completely penetrated tacks, and flush surfaces have already started to pay their dividends.

The 12-gage axle housing prefabricated by fillet welding and the $^3/_8$-in. thick caster plate (Fig. 10) are positioned and fillet welded to the 14-gage truck bottom.

Filler material is added. Final grinding on the interior surfaces provide a smooth sanitary product. Grinding of the outside seams is not required, but the whole tub is acid dipped (Fig. 11) to provide a clean pleasing appearance.

Many of the weldments are relatively small as illustrated by the sausage feeder tube shown in Fig. 12. The three basic parts are joined by two welds. The operator holds and rotates the parts by hand. Normally the welders wear gloves to protect their hands from arc burn among other things, but this operation is of relatively short duration. The finished welds and finished product is shown in Fig. 13.

Fig. 11 The completed tank is pickled in acid to give it a bright finish

Fig. 12 Welding a feeding tube for casing flusher

Meat conveyor table pans have their corners formed by alternate welding and hammering operations. The corner cut outs are made to a developed shape while the sheet is flat. The edges are flanged and then the sides and ends rolled up. After the corners are tacked, a short section adjacent to the weld is hammered closed (Fig. 14) and then welded. This operation is progressively repeated along the joint line until the gap is completely closed and welded. As in a previous operation, the underbead is smoothed by a high-speed welding pass prior to grinding.

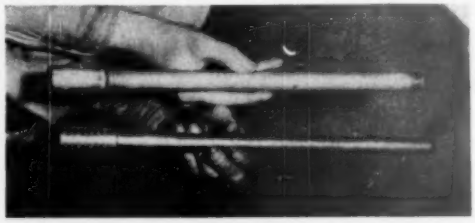


Fig. 13 Feeder tubes—as-welded and finish machined

Fig. 14 Meat pan for conveyor table. Corners made by repeated welding and pounding

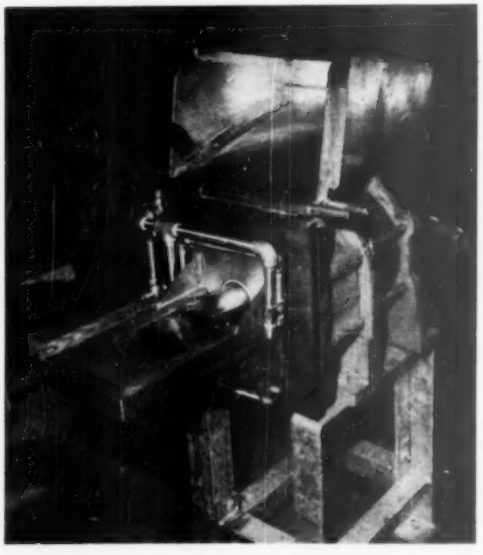


Fig. 15 Dehorning machine cover welded of stainless steel

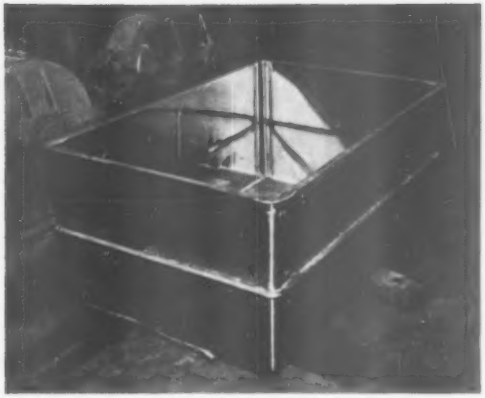


Fig. 16 Meat pickling tank, made of stainless steel

Fig. 17 Welding stainless steel boxes for cleavers and knives

This air-operated animal dehorner (Fig. 15) exemplifies the rugged construction required for most packing house equipment. This machine is used by meat packers to quickly shear horns from cattle heads. It operates by placing the horn between two knives and applying air pressure to the cylinder by means of a convenient foot valve. The machine is pneumatically actuated and is designed to operate with minimum air pressure of 60 lb. With one operator this machine can shear 80 heads per hour. Formerly this operation was performed on a band saw. The operator held the head between his hands and forced the horns against the saw blade. An expert operator could shear from 20 to 30 heads per hour working at top speed. The hood is inert-gas-shielded arc welded from $^3/_{16}$-in. stainless steel plate.

The pickling tank shown in Fig. 16 is fabricated from 14-gage stainless steel using techniques similar to the truck tank already discussed. The specifications, however, require welding a $^3/_{16}$- by 1-in. bar on edge completely around the center. About 50 ft. of fillet welding is necessary. Note particularly the absence of distortion, which we feel is remarkable for this size weldment.

Sanitary rules in the meat packing industry require a butcher to wash his hands and sterilize his instruments before starting work after leaving the floor. Convenient welded stainless steel unit washstands with hospital-type foot controls are spotted strategically for this purpose. In addition to the hand washing facilities, each stand is equipped with welded stainless steel boxes containing a sterilizing solution for his cleaver, knives, etc. Two sizes of these boxes are being welded here (Fig. 17). An inside finish grinding operation and an acid dip completes these items.

In general, the inert-gas-shielded arc-welding process has fitted into our fabricating procedures very nicely. The equipment and operation is simple and the technique of handling it can be readily absorbed by competent welders. It has a number of advantages. Probably of prime importance are the dollar savings in rod and grinding costs—weld reinforcement is even more expensive to remove than to apply. Highly concentrated heat application minimizes distortion, resulting not only in reduction of finishing costs, but also in a smoother, better looking product. In most cases welds can be made in one pass from one side—again representing lower cost through faster over-all welding. Spatter and flux are eliminated.

The transition to sanitary stainless steel construction in the meat packing industry is assuming major proportions and this newest of welding processes is doing its share in easing us over the fabricating humps. Lord Kelvin once said, in substance if not in words, that mathematics is no earthly use until it has been turned into arithmetic. In other words, the quantitative perspective can be acquired only by repeated figuring, visualizing and checking by experiment. As you have seen, we are far beyond that stage and in the future we can look forward to newer, better and more efficient products for our consumers through the use of inert-gas-shielded arc welding.

"Heliarc" Welding in the Automotive Industry

This process is inherently suited to the automotive industry because high-quality welds can be made at high speeds at low cost. Information is given on equipment, methods and procedure

by R. H. Bennewitz and F. J. Pilia

INTRODUCTION

APPROXIMATELY two years ago Linde introduced its inert gas-shielded arc-welding process—"Heliarc"* welding—to the automotive industry for the welding of two-piece fenders. This first successful application of the process has resulted in its use on body joints, bumper guards, bumpers and other accessory parts requiring metal finishing. The process permits the elimination of soldered joints, higher quality parts, simplified dies, reduced finishing costs and improved surfaces for paint. Expanded use of the process promises to greatly revise automotive sheet metal joining procedures.

ACCEPTED JOINING PROCEDURES

When the problem of joining sheet metal confronts the engineer, he is forced to make a selection from the following list of welding methods or some variation thereof:

1. Gas welding.
2. Metallic arc welding.
3. Heliarc welding.
4. Atomic hydrogen welding.
5. Resistance welding.

Where metal finishing is not a problem, selection of the proper process is not difficult and we do not propose or suggest that Heliarc welding can necessarily contribute anything to accepted procedures. When the body engineer receives the layout drawings from the styling department, he is faced with the problem of deciding whether various parts can best be made by drawing the parts in one piece or by using simplified dies and joining the parts by welding. In the past, it has been the practice to resort to welding only where it has been impossible to draw the section in one piece. Examples of accepted joining procedures are the coach joint and joggle lap joint, used in joining the roof to the quarter panel and the upper rear deck extension to the quarter panel. These joints are usually spot welded, filled with body solder and finished to the proper contour. In some cases, the sheets are either butted or lapped and then brazed. The joint is subsequently depressed, filled with solder and finished to the proper contour. Very often, the engineer would prefer to make two stampings and join them by welding in order to reduce the cost of complicated dies and, also, to minimize scrap losses resulting from difficult drawing operations. However, in considering gas, metal arc, atomic hydrogen or various resistance-welding processes, he may find that he has to forego welding because of inadequate strength obtainable with these methods, poor appearance of the finished product or cost of the most acceptable method available.

APPLICATION OF HELIARC WELDING

The Heliarc process is inherently suited to the requirements of the automotive industry because high-quality welds can be made at high speeds with no slag or spatter, a minimum of reinforcement, controllable distortion and low cost. Other methods of welding, while they may produce sound, high-quality welds at a reasonable cost and speed, do not lend themselves well to metal finishing and produce distortion beyond the limits of acceptability. The concentrated high-temperature arc (arc temperature approximately 6000° F.) of the Heliarc process permits welding at a rapid rate with very little dissipation of heat into areas surrounding the weld. The simplicity of the torch and its limited size permit easy access to the rather confining fixtures employed with its use. The welds are of a high quality and there is no slag or spatter due to the fact that the weld area is blanketed by argon gas which

R. H. Bennewitz is Supervisor of Process Service and **F. J. Pilia** is Development Engineer, The Linde Air Products Co., New York, N. Y.

Presented at the Thirtieth Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

* The term "Heliarc" is a registered trademark of The Linde Air Products Co.

forms a completely inert-shielding medium. The process lends itself well to high production because a minimum of skill is required and the training of operators does not present a difficult problem. In many instances women welders are employed. The concentrated arc permits ease of controlling the weld puddle and the surface tension of the weld puddle permits ready control of the weld deposit in all positions. Accurate control of the weld deposit, of course, permits holding the weld bead to a minimum, thereby permitting rapid finishing.

From this brief description of the advantages of heliarc welding over other welding methods, it can be seen that it is ideally suited to automotive sheet metal joining. On joints now being welded by other methods, the quality, strength, finishing, appearance, over-all speed and cost can be improved greatly through the adoption of Heliarc welding. The process further permits considerably increased freedom of design, simplification of dies through the use of multiple stampings and reduced maintenance costs through the elimination of operations required with other welding methods.

TYPICAL APPLICATIONS

The use of Heliarc welding in the fabrication of front fenders was one of the first applications of this process in the fabrication of automobile bodies. Figure 1 shows a typical fender that was stamped in two parts

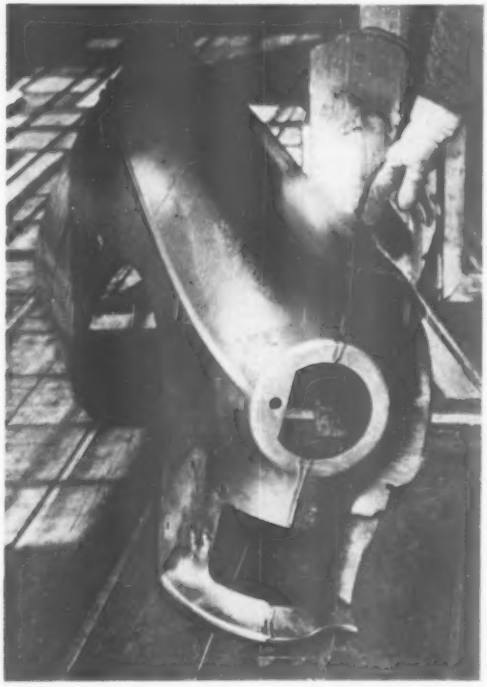


Fig. 1 Typical front fender fabricated by "Heliarc" welding

Fig. 2 This bumper, designed in the modern style, is easily fabricated by welding

Fig. 3 The welded bumper guard is easily fabricated from two stamped parts

and joined by Heliarc welding. The welded bumper in Figure 2 is another example of the use of welding to simplify dies and stamping operations on this part. Similarly, welding makes it possible to produce a bumper guard that would be impossible to draw or stamp. The guards shown in Fig. 3 were easily made by Heliarc welding.

On the body itself, a straight flat-butt weld shown in Fig. 4 is now being used by one manufacturer to join the upper deck extension to the quarter panels. Designs used to call for a flanged-in seam at this location, or for the joint to be brazed, depressed and filled with solder. The Heliarc weld shown has ample strength and can be quickly ground flush to give a smooth surface for the enamel finish. These are some of the typical applications on automobile fenders, bumpers, bumper guards and bodies that have proved themselves economically sound under high-production conditions and are continually being expanded.

FIXTURE REQUIREMENTS

The Heliarc process in its successful application requires careful attention to the fundamentals of fixture design.

The basic functions of a good fixture are to assure proper alignment of the parts, limit distortion, provide a backup for the weld and maintain dimensional toler-

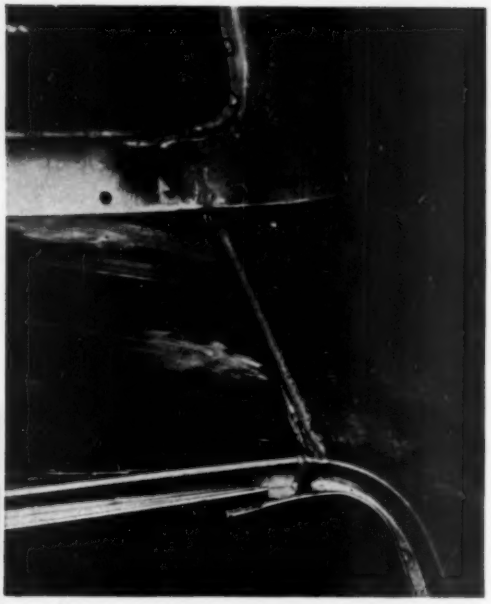


Fig. 4 Two flat-butt welds join the upper-deck extension to the quarter panels

ances. In order to fulfill the aforementioned requirements of a good fixture, the following points must be considered:

1. Hold-Down Pressure. The upper section of the fixture clamps the parts down on the back-up bar. The pressure should be from 300–500 lb. per lineal inch per side for material under 0.050 in. in thickness. Furthermore, this pressure should be exerted over a 1-in. width along the weld line (Fig. 5). A secondary contact area of 1 in. in width is desirable, with the area between the contact areas being relieved.

2. Contours. Because of the nature of automotive parts, most of the fixtures will require contoured backups and matching contoured hold-downs. It is imperative that the fixtures be carefully "spotted-in" until accurate holding is obtained continually along the contact areas. Spotting-in is accomplished by the addition or removal of metal to areas indicated to be low or high upon trial clamping on actual stampings. Final spotting-in must include the actual welding of parts in the fixture to determine the location of hot and cold areas.

Fixtures for completely flat work are much less of a problem since, if machining has been accurate, there should be no need for spotting-in.

3. Important Dimensions. Certain basic dimensions must be maintained on hold-downs and backups or the success of the process will be impaired. First of all, the fixture parts must be structurally massive enough to resist distortion when holding pressure is applied. Secondly, the dimensions indicated in Fig. 5 must be held, since empirical data has proved these dimensions critical.

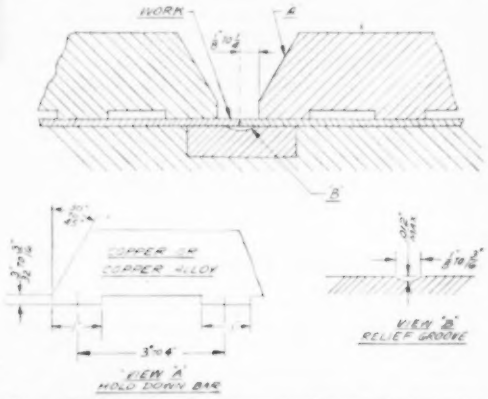


Fig. 5 This drawing shows important details for designing successful fixtures

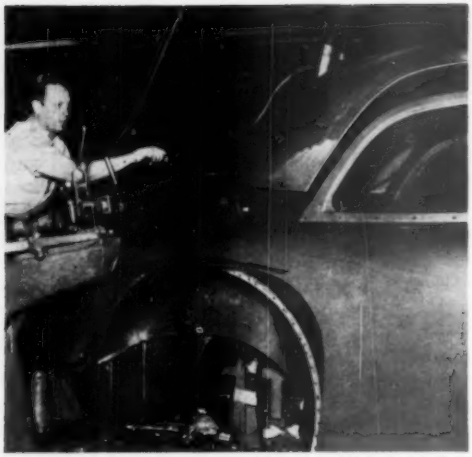


Fig. 6 The roof section is added to the rest of the body assembly while it is in the main-framing fixture

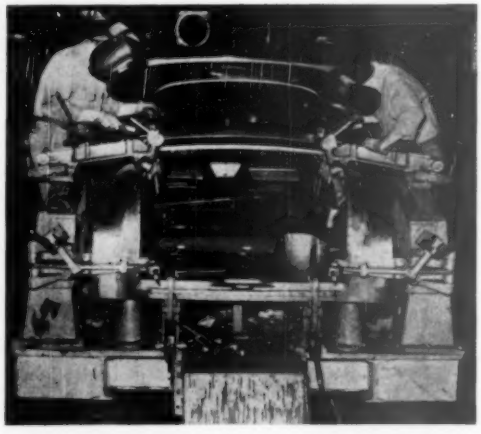


Fig. 7 Two operators simultaneously weld the upper deck extension to the quarter panels

4. Materials Used. The strength members in the fixture are open to a choice of steel plate, cast steel or cast iron. The back-up bar should be beryllium copper and the hold-downs should be either beryllium copper or aluminum bronze. The use of copper or wear-resisting copper alloys is necessary to aid in conducting heat from metal adjacent to the weld, thereby aiding the control of distortion. Furthermore, these nonferrous materials aid in eliminating the magnetic effects often set up in fixtures, which adversely affect the control of the arc. The use of these materials also prevents fusing the work to the fixtures and provides a convenient surface on which to strike the arc without "alloying" the tungsten electrode.

Hasty analysis of the fixture requirements for the process may result in the false conception that the requirements are too stringent and expensive. However, more careful consideration will reveal that if all the basic fundamentals are fully appreciated by those working on the fixtures, very little more work will be required to produce a satisfactory fixture than that required to produce one unsuitable for the process.

In considering the design of fixtures, the next three photographs show how an extremely simple fixture is used for making a weld on a car body. Figure 6 shows the stage of assembly in which the roof is lowered on to the rest of the body assembly in the main-framing fixture. The operators in Fig. 7 are joining the upper deck extension to the quarter panels as the assembly moves along the line. Figure 8 shows the simple fixture used to make this joint. The back-up bar is

Fig. 8 A small fixture is used for this body weld

The back-up bar is inserted through the trunk opening and latched through the rear window

Fig. 9 These two stampings are the first step in making a bumper guard

Fig. 10 Stampings for the bumper guard are inserted into the fixture face to face. The jaws are forced together by mechanical linkage

inserted through the trunk opening and is latched onto the hold-down frame through the rear window.

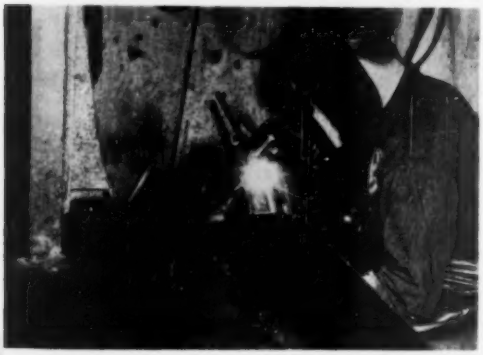


Fig. 11 Welding the bumper guard
The operator turns the fixture by hand as welding progresses

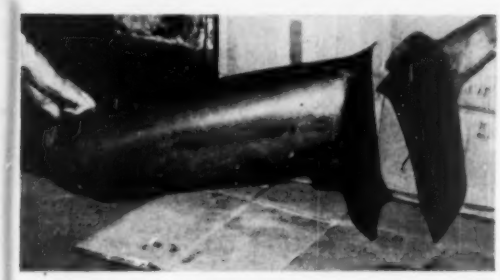


Fig. 12 A modern bumper with vertical arm is made from two stampings

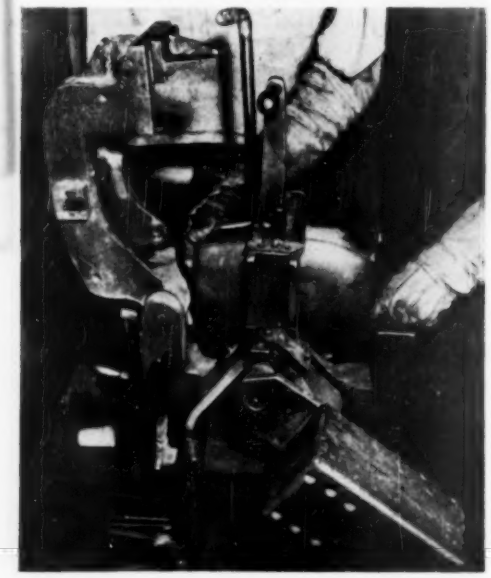


Fig. 13 Loading the bumper-welding fixture
Mechanical linkage holds the parts in alignment for welding

Several manufacturers have adopted the process for welding bumper guards after careful cost and quality studies. Figure 9 shows the two simple stampings that make up this part. The operator inserts these into the fixture shown in Fig. 10. A toggle link closes the fixture which holds the stampings face to face. The operator turns the fixture as welding progresses (Fig. 11) so that the weld is made in the down-hand position.

Present design in bumpers is something entirely different from the slightly curved strip of steel that used to protect our ears. Figure 12 shows the two stampings that are now used for the welded bumper. The parts are inserted into the fixture shown in Fig. 13 for welding. End pressure is applied to force the small stamping against the long piece. The hold-down plate latches

Fig. 14 Two stampings for a front fender call for welds on the top and on the front face

Fig. 15 Loading the large stamping into a front fender welding fixture

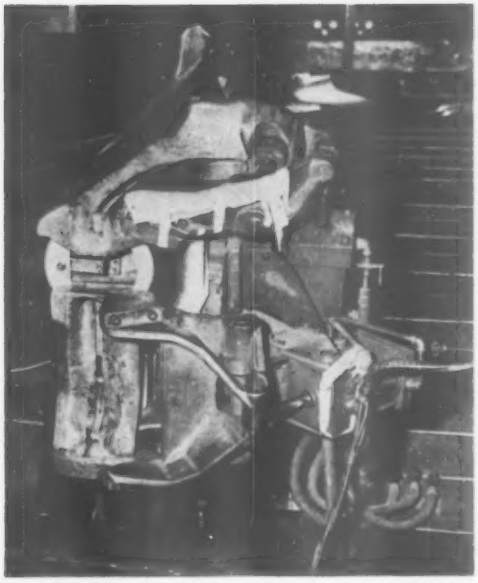


Fig. 16 The fixture is locked and swung to the horizontal position for making the weld on top of the fender

down over the seam and holds the parts against the back-up plate for welding.

More massive fixtures are used for the fenders. A typical two-piece front fender is shown in Fig. 14. The operator in Fig. 15 is loading the parts into the fixture which is then closed and swung to the horizontal position (Fig. 16) for making the weld on the top of the

Fig. 17 The fixture can be positioned for operator comfort

Making the weld on the front of the fender

Fig. 18 This design of rear fender is also fabricated by welding

fender. The fixture can be positioned for ease in loading and also for operator comfort. In Fig. 17 the operator is making the welds on the front of the fender with the fixture in the tilted position.

On certain makes of car, welding is used in making the rear fenders also. Stampings for this assembly are shown in Fig. 18. Details of the fixture can be seen in Fig. 19 which is open for loading the parts. In Fig. 20 the operator, a woman in this case, is making the weld on the top of the fender. Notice the heavy clamps that keep the parts in alignment and help to prevent

Fig. 19 Loading the parts into the rear-fender welding fixture

Fig. 20 The rear fender fixture is closed and welding is in operation

distortion. Figure 21 shows the location of the welds in the completed rear fender.

Another type of fixture is used to fabricate a slightly different style of front fender shown in Fig. 22. The two stampings are on the right and the completed fender is on the left. Figure 23 shows the general construction of the fixtures. Hydraulic pressure forces the upper portion of the fixture down onto the workpiece with sufficient pressure to bring slightly inaccurate contours into proper alignment. The welding platform is built

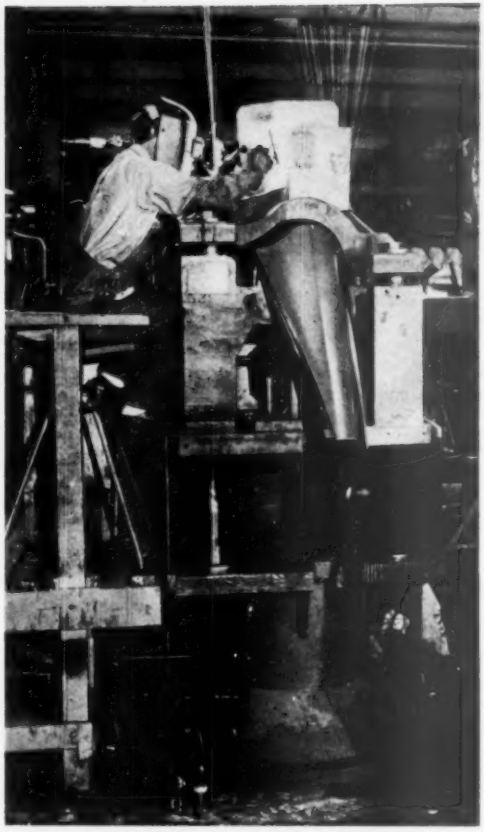


Fig. 23 (Right) Details of the hydraulic fixture for welding the front fender

Fig. 21 Two welds complete the rear fender

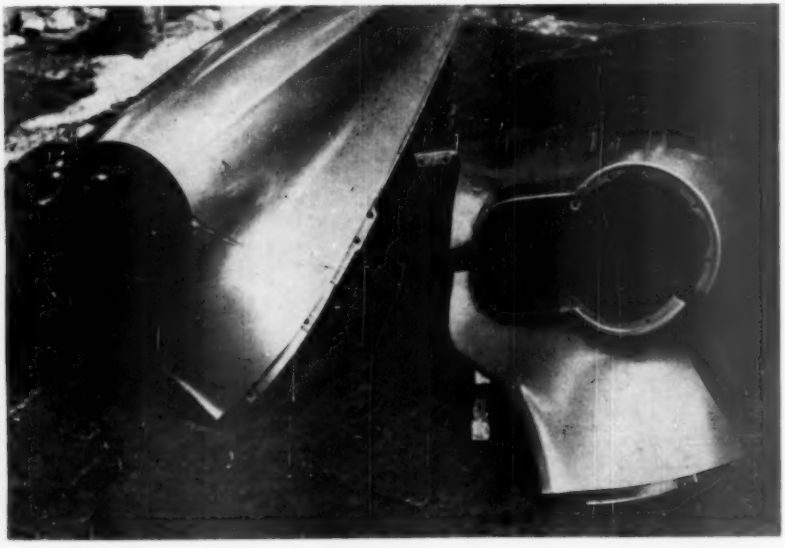


Fig. 22 A front fender with simpler contours is shown before and after welding

a few feet above the floor level to accommodate the fixture and also to make it easy to load the large stamping into the fixture. Two operators work simultaneously, one making the weld on the top of the fender, the other welding the joints on the front beneath the headlight and grille openings. Figure 24 shows the welding stations in more detail.

EQUIPMENT REQUIREMENTS

1. The Torch. The Heliarc torch (Fig. 25) is of the utmost importance since it must be light, well-balanced, easily adjustable, trouble-free and permit ease of access to the fixture. The torch has an electrode holder easily adjusted by a slight turn of the electrode extension cap; the water-cooled copper cup is of minimum size and has a long life; the power cable is water cooled thereby permitting maximum current (250 amp.), minimum diameter and maximum flexibility. Another type of torch suitable for use with a.-c. and d.-c. current and more general application of the process is shown in Fig. 26. This torch was originally used on automotive work, but has since been replaced because the cups were too large for good accessibility to the fixture.

2. Power Source. Direct current is the preferred source of power and most 200-amp. motor generator sets will be satisfactory, providing they employ sensitive adjustment of current.

A portion of the d.-c. generator power supply in a large automotive plant is illustrated in this view, Fig. 27. Note that the gas controls and time delays are mounted with the generators.

3. Shielding Gas. Argon gas has been found to be the most suitable for these applications because it is more economical to use and permits a greater degree of manual arc control. The higher cost of helium results not only from cost of product, but from cylinder handling, increased floor space requirements and a few operating handicaps affecting labor. Gas is generally piped to use points from a manifold such as the one shown in Fig. 28.

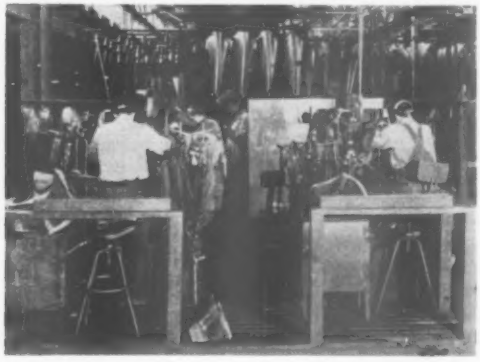


Fig. 24 The operators' stations are on a raised platform to accommodate the height of the fixtures

Four fixtures with eight operators are included in this production unit

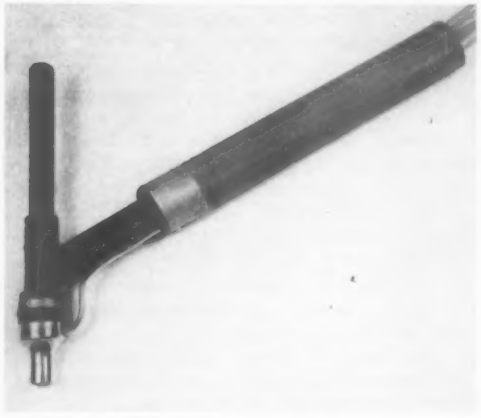


Fig. 25 The Heliarc HSH-3 welding torch was designed for d.-c. welding applications

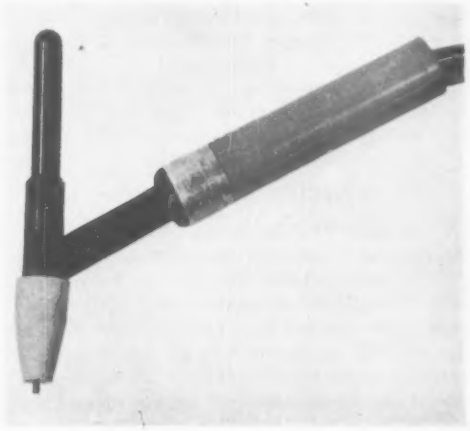


Fig. 26 The Heliarc HW-4 torch is widely used for general applications

Fig. 27 In this large automotive plant, note that argon controls and time delays are mounted with the generators

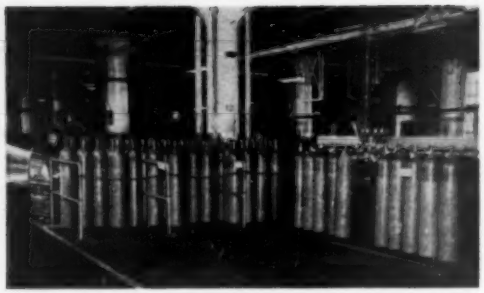


Fig. 28 Argon is usually piped to use points from a manifolded supply

Note the adequate storage space for full and empty cylinders

4. Gas Controls. In the interest of economy, it was found essential to automatically control the flow of argon gas. A solenoid valve opens allowing the continuous flow of a metered amount of argon. Upon extinguishing the arc, the control allows the continued flow of a sufficient amount of gas to cool the tungsten electrode. This results in economical use of tungsten electrodes, prevents gas wastage and promotes high-quality welds.

A gas regulator is necessary to reduce the cylinder pressure to a working pressure of 25 psi. and a flowmeter is also required to control the volume of gas used.

CONTROL OF STAMPINGS

1. Tolerance of Joint Fit-up. The importance of joint fit-up must not be overlooked, since it affects not only the quality of the weld but also influences the speed of welding, finishing and final cost. As would be assumed, the best condition from all standpoints is a joint in which the sheet edges are in metal-to-metal contact. Perfect conditions are, of course, not always possible and serious handicaps are not suffered if the sheet edges are not separated by more than the thickness of the material being welded. It is possible, if necessary, for example, to weld a joint where the sheet edges are separated by $^1/_8$ in. on 0.050-in. stock. However, such extreme spacing makes welding difficult and increases the total cost of the finished product.

2. Material Control. While the analysis and quality of the steel are important, it is only necessary that these qualities satisfy normal specifications. "Off-analysis" steel, high in sulphur, phosphorus or other objectionable elements, may cause welding difficulties. Extreme variations in material thickness, abnormal "springback" and abnormal hardness will cause welding difficulties because of their effect on holding required tolerances when clamped in the fixture.

3. Stamping Contours. Consistency in stamping contours is essential, since variations will affect joint fit-up and proper holding of the parts in the fixture. Heliarc welding can be done in all positions, but, as in other welding processes, the best and fastest work can be done in the down-hand position. Therefore, on contour work, the fixture positions the work so that all welding will be done as close to down-hand as possible. Where a choice is possible on weld location, careful consideration should be given to the advantages of down-hand welding.

A die trim should be the final operation on stampings to be subsequently welded. If a die trim is not used, difficulties with joint fit-up can be expected, which will be more costly than the die trim.

THE "HELIARC" WELD

1. Without Added Filler Metal. Most of the welding on automotive work is done without the addition of filler metal in the interest of reducing cost. It sometimes becomes necessary to add filler metal when joint fit-up is poor. It is also necessary to add filler metal when going over a section already welded or when restarting a weld. In general, however, if the weld can be made without filler metal, it is advantageous to do so because higher speeds and lower final cost will result.

2. Addition of Filler Metal. Frequently it is necessary to add filler metals because of poor joint fit-up and poor holding properties in the fixture. Addition of filler metal makes it possible to salvage parts which would otherwise be scrapped. In many cases, poor quality steel can be salvaged, if necessary, by the addition of filler metal. It is difficult to weld steel which has not been fully "killed" with the process unless filler metal is added. The amount of rod required to produce porous-free welds is very slight, but a small quantity must be added at regular intervals or porosity will result. It should be pointed out here that, in general, it is not possible to make high-quality welds with the process in hot-rolled sheet either with or without filler metal.

The function of filler metal in eliminating porosity is that of cleaning the weld by injecting a "killing" action on the weld puddle. We have found that a chrome-manganese-silicon rod works very nicely for this purpose. Such filler rods as Norway Iron and low-carbon mild steel are not normally suitable.

3. Torch Angle. It is a matter of conjecture as to what torch angle is proper. The angle employed seems to vary with the operator. In general, an angle of approximately 15° to the work is used. This permits good visibility of the joint, electrode and puddle, thereby contributing to higher speeds.

4. Electrode Extension. The length of electrode extension beyond the end of the gas cup varies with the torch angle employed and, therefore, is somewhat dependent upon the operator. Good practice, however, dictates that the electrode extension should not be greater than $^1/_2$ in., preferably $^1/_4$ to $^3/_8$ in.

5. Gas Flow. For the welding of automotive sheet in thicknesses under 0.050 in., the recommended gas flow is from four to five liters of argon per minute. The necessity for higher gas flows indicates faulty equipment, poorly designed equipment, improper gas cup

size, improper fixture design or interference from drafts or artificial air currents.

6. Current. On the welding of material thicknesses from 0.037 in. to 0.050 in., the current employed should fall in the range from 110 to 160 amp. d.-c. straight polarity. Again, it is difficult to definitely fix the current for a given material thickness because contours and operator's proficiency will be determining factors. Since d.-c. straight polarity has proved so far superior on this work, it does not seem to be worth the time to discuss here the advantages or disadvantages of a.-c. vs. d.-c. power.

7. Welding Speeds. It is possible to realize welding speeds of 16 to 40 in. per minute when Heliarc hand welding is employed. Such speeds have been proved on production applications consistently, and are attributed to the high temperature concentrated arc employed and the unobstructed visibility of the weld puddle due to the absence of smoke and spatter. High speeds, of course, can only be obtained where complex contours are not involved and where fit-up and hold-down conditions are good. We have previously pointed out that higher speeds (approximately 20% higher) can be obtained when mechanized welding is possible.

WELDING COSTS

The cost of "Heliarc" welding will generally be greater than for other welding processes if no consideration is given to the other savings realized as a result of its use. Preceding remarks have covered the advantages gained by using the process and they will be summarized in the conclusions of this paper.

Production applications on fenders and bodies of 0.037-in. stock have resulted in the following costs:

	Per lineal inch
Argon gas	$0.00123
Tungsten electrode	0.00004
Power	0.00003
Labor	0.00684
Approximate total cost	$0.00814

While not a welding cost, it probably should be pointed out here that finishing of 0.037-in. stock will cost about as follows:

	Per lineal inch
Sanding disks	$0.0022
Labor	0.0118
Approximate total cost	$0.0140

It must be mentioned that this cost for finishing covers not only the weld area but all of the surrounding area requiring finishing. The figures given for welding and finishing are empirical averages which will not necessarily apply to all contours and all production applications. On a flash-welding production application, involving 18 in. of weld on 0.037-in. stock, the welding and finishing costs were $0.038 per lineal inch.*

This figure, when compared with costs for welding and finishing Heliarc welds of equivalent length, contours and same thickness of material, indicates a cost advantage in favor of Heliarc welding of approximately 40%.

The process has been applied to the welding of bumper guards and bumper brackets with material thicknesses in the range of 0.100 in. The welding costs are approximately as follows:

	Per lineal inch
Argon gas	$0.00172
Tungsten electrode	0.00005
Power	0.00008
Labor	0.00232
Total cost	$0.00417

It can be seen from the cost figures presented that costs are unpredictable. It would be expected that the heavier material welding costs would be greater. Normally, heavier material costs are higher, but conditions vary from plant to plant with regard to weld requirements, labor costs, size of parts, handling required, etc. This example should indicate the wisdom of investigating each possible application on its own merits.

CONCLUSIONS

Modern automotive styling has complicated drawing operations to the extent that it is more economical to employ multiple section stampings than to attempt drawing in one piece. Heliarc welding presents unique advantages heretofore unobtainable from welding processes employed by the automotive industry. On automobile bodies, the following advantages will result from the use of the process:

1. Elimination of solder and extensive finishing.
2. Elimination of "solder mat" and improved paint finishes.
3. Stronger and higher quality welds.
4. Reduced finishing costs over other welding processes (metallic arc, flash welding, etc.).
5. Simplification of dies.
6. Less scrap loss.
7. Lower maintenance costs due to elimination of operations.
8. Greater freedom of design.

In addition, on other component parts of the car, such as fenders, bumpers, bumper guards, etc., the following advantages will result:

1. Freedom of design on difficult contours by permitting the joining of multiple stampings.
2. Simplification of and less costly dies required.
3. Improved appearance and maximum strength.

* The flash welding and finishing costs combined above includes welding, maintenance of flash welder jaws, rejects, salvage and finishing.

4. Reduced finishing costs.
5. Higher production.
6. Reduced maintenance.
7. Decreased scrap.

All of the advantages referred to can be obtained without presenting any production problem with the training of operators and with a minimum capital investment for fixtures and equipment.

Circuit Analysis of Frequency-Changer Welders

Discussion by F. L. Brandt, R. T. Vredenburgh and L. S. Wilkins

Mr. Boice has spent many months of study and experimentation upon the subject. We have had but a very short time to review his work. As welder manufacturers, we are keenly interested and most appreciative of his work. Our principal interest at this time is to use his formulas with experimental data. We have taken readings on a typical model 4 size, 42-in. throat spot welder with low-frequency changer or converter. The application is as follows:

$$E_{do} = \frac{1.17E \cos a}{N} = E_{Sec.}\ \text{No Load} \qquad (1)$$

$$E_{do} = \frac{1.17 \times 440 \times 1}{62} = 8.2\ \text{Volts}$$

$$I_S = \frac{E_{do}}{R + (3X_{pp}/4\pi N^2)} = I_{Sec.}$$

$$= \frac{8.2}{0.916/62^2 + [(3 \times 0.183)/4\pi 62^2]} = \text{Peak} \qquad (3)$$

33,000 Amp.

Measurement of X_{pp}-Impedance test at 60 cycles. All three coil arrangements on Fig. 1 gave the same values within the error of the pointer stop instruments.

E	I	W
132 Volt	565 Amp.	37,000 Watts

This was repeated at half the voltage and gave practically the same relation.

By calculation

VA	$P.F.$	Z	R	X_{PP}
64,580	0.67	0.238	0.152	0.183 Ohm

Mr. Boice reports that:

$$(R/N^2)/(3X_{pp}/4\pi N^2)$$

is between 0.05 and 0.3.

By substitution

$$(0.152/62^2)/0.0000113 = 0.35$$

The turns ratio of the transformer is peculiar with respect to the amount of core for 60-cycle and other design characteristics.

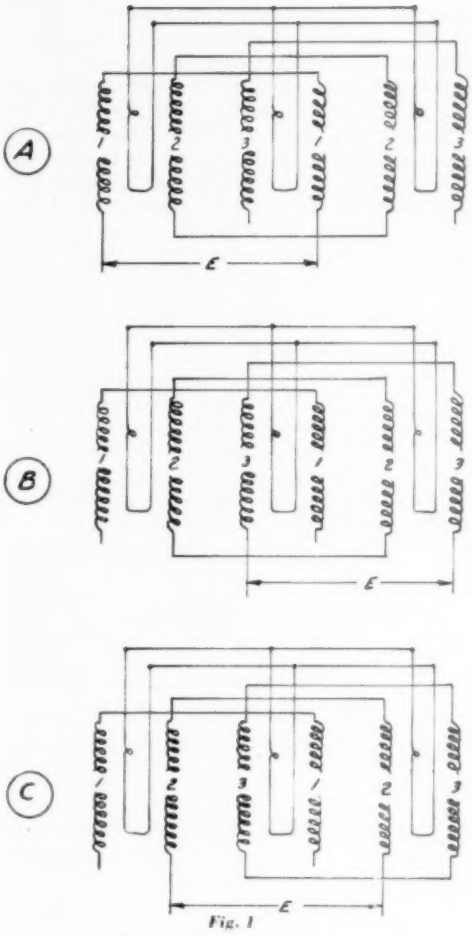


Fig. 1

$$E_d = E_{do} - \left(\frac{0.3x_{pp}}{4\pi N^2}\right) I_S \qquad (2)$$

$$= 8.2 - (0.0000113 \times 33{,}000) = 7.83\ \text{Volts}$$

$$i_s = \frac{KE_{do}}{\sqrt{R + (3x_{pp}/4\pi N^2)^2 + N^2}} = I_{Sec.}\ \text{Rms.} \qquad (4)$$

$$= \frac{0.91 \times 8.2}{[(0.916/62^2) + 0.0000113]^2 + [1.55/(62^2 \times 5)]}$$

$$= 29{,}300\ \text{Amp.}$$

F. L. Brandt, R. T. Vredenburg and **L. S. Wilkins** are with the Thomson Electric Welder Co., Lynn, Mass.

The paper by W. K. Boice was published in the October 1949 WELDING JOURNAL, pp. 946–956.

An oscilloscope was used to check this value experimentally. The test revealed that the calculated value is at least 10% low.

R and X were determined experimentally by applying 60-cycle power to one primary winding (others open circuit) and short-circuitig the secondary with a manganin shunt.

E	I	W
254 Volt	140 Amp.	18,000 Watts

By calculation

VA	$P.F.$	Z	$R^{60\ cyc.}$	$X^{60\ cyc.}$
35,560	0.506	1.81	0.916	1.55

Ratio of

$$X/R = \frac{1.55}{5 \times 0.916} = 0.34$$

which is somewhat lower than 0.5 − 1.5 for which $K = 0.91$.

$$I_p = \frac{i_s}{N\sqrt{3}} = \frac{29{,}300}{62\sqrt{3}} = 273 \text{ Amp.} \quad (5)$$

$$I_{LP} = I_S/_N = \frac{33{,}000}{62} = 533 \text{ Amp.} \quad (6)$$

(peak line)

$$I_L = 0.815 \qquad I_{LP} = 434 \text{ Amp.} \quad (7)$$

(rms. line)

$$i_L = I_L \qquad \frac{i_s}{I_S} = 434 \times \frac{29{,}300}{33{,}000} = 385 \text{ Amp.} \quad (8)$$

(rms. line $^1/_2$ cycle)

$$I_{LV} = 0.674 \qquad I_{LP} = 358 \text{ Amp.} \quad (9)$$

(rms. line freq. comp.)

$$i_{LV} = I_{LV} \qquad \frac{i_S}{I_S} = 318 \text{ Amp.} \quad (10)$$

(rms. line freq. comp. phase shift)

The remaining values for KVA and Power may be calculated from these values.

Discussion by M. S. Shane and Perry L. Nies

The discussion is intended to be a qualitative amplification of the electrical advantages of the welder as developed and illustrated by formulas in the paper. Disadvantages are likewise noted.

The equivalent circuit should be helpful in relating numerous equations involving average and maximum values of performance in the secondary circuit.

ELECTRICAL ADVANTAGES

1. Reduced kva. demand.

The lower kva. demand of the frequency-changer welder as compared to the conventional single-phase welder depends in part on full commutation of primary current to all three phases, thus distributing the demand to all phases. The minimum heat time for full three-phase commutation with balanced line currents is 19 millisec. or 1$\frac{1}{2}$ cycles for 60 cycles per second frequency. For shorter heat times the demand is carried by one or two phases only, resulting in unbalanced operation. Hence for heat times of longer than 19 millisec., the kva. demand of the frequency-changer welder is divided between three phases, reducing the kva. demand per phase well below that of a comparable single phase welder.

The lower kva. demand of the frequency-changer welder further depends on the longer pulse (heat) time resulting from low-frequency operation. Welder reactance and resistance are less at low frequency than at the higher 60 cycles per second, thus reducing the total and per phase kva. demand needed to deliver a specified load current.

The pulse time can be adjusted on frequency-changer welders from 17 to 100 millisec., this being one to six cycles of 60 cycles per second frequency. For certain applications a longer pulse time of 333 millisec. (20 cycles) can be obtained by increasing transformer iron proportionately. The rate of current rise is decreased, prolonging the induced voltage period on which the pulse depends. Kva. demand is a minimum in this application.

2. Improved Power Factor. Improvement in power factor results from lowering frequency with associated decreases in reactance. As secondary pulses become longer, they more closely assume d.-c. characteristics with unity power factor.

The representation in the paper of vector power factor should be used with care. While applicable in computing secondary voltage drop, vector power factor is not used by power companies in billing. Rather than 75 to 95% (p. 15), the lower rms. power factor of 62 to 78%, obtained by use of the distortion factor of 0.826 (p. 16), would be used for billing purposes.

3. Less Disturbance on Supply Systems. As previous discussion indicates, reduced kva. demand will result in less disturbance on the supply system; i.e., less line current with less voltage drop.

This, in practice, has not proved as attractive as hoped. Line drop caused by the three-phase frequency-changer welder was perhaps only $^1/_4$ as great as with a single-phase welder doing the same job, but the flicker caused by the three phase welders was more objectionable to the average observer's eye, as it was of low frequency.

4. Equivalent Circuit. A simple equivalent circuit showing average and maximum values of secondary no-load voltage, load voltage, voltage regulation, current, kva., power and power factor can be established from equations given in the paper.

The equivalent circuit shows the dependence of voltage regulation on X_{pp}, as brought out in the paper. It also shows the strange nature of X_{pp} a sort of wattless resistor. An attempt to apply Equation 20 shows that X_{pp} cannot be considered as an ordinary inductor.

M. S. Shane and **Perry L. Nies** are with the Cleveland Electric Illuminating Co., Cleveland, Ohio.

This point is not made clear in the paper.
Equation 20:

$$(PF)_{LV} = \frac{R}{R + (3X_{pp}/4\pi N^2)} \cos a$$

If X_{pp} were reactive, Equation 20 would be:

$$(PF)_{LV} = \frac{R}{\sqrt{R^2 + (3X_{pp}/4\pi N^2)^2}} \cos a$$

Nomenclature

a	=	angle of phase retard beyond normal full heat angle. With no retard, $a = 0$ and $\cos a = 1$.
E	=	rms. primary voltage.
E_{do}*	=	average no-load secondary voltage.
E_d*	=	average secondary voltage.
I_s	=	maximum secondary current.
$(KVA)_{LV}$	=	maximum vector kva. input
N	=	turns of one primary/turns of secondary.
P	=	maximum power input.
$(PF)_{LV}$*	=	vector power factor of line input.
R	=	total resistance of *weld*, welder, secondary and one primary (referred to secondary).
X_{pp}	=	average reactance between primaries (at supply frequency).

Equations (from author's paper):

$$E_{do} = \frac{3\sqrt{3}\cos a}{\sqrt{2}\pi N} \times E \quad \text{Eq. (1), p. 6}$$

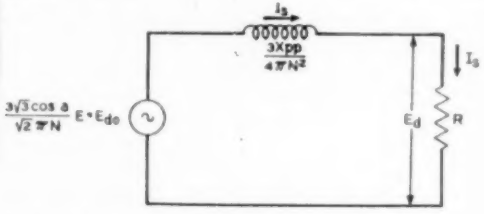
$$E_{do} = E_d + \frac{3X_{pp}}{4\pi N^2} I_s \quad \text{Eq. (2), p. 8}$$

$$E_{do} = I_s R + \frac{3X_{pp}}{4\pi N^2} I_s \quad \text{Eq. (3), p. 9}$$

Hence:

$$E_d = I_s R$$

From these equations we derive the following simple circuit:



The following equations are also satisfied.*

$$(KVA)_{LV} = \frac{E_{do} I_s}{\cos a} \quad \text{Eq. (15), p. 14}$$

$$P = RI_s^2 = E_d I_s \quad \text{Eq. (16), p. 14}$$

$$(PF)_{LV} = \frac{P}{(KVA)_{LV}} \quad \text{Eq. (19), p. 15}$$

$$(PF)_{LV} = \frac{R}{R + \frac{3X_{pp}}{4\pi N^2}} \cos a \quad \text{Eq. (20), p. 16}$$

Combining Equations (15) and (16):

$$(PF)_{LV} = \frac{E_d}{E_{do}} \cos a \quad \text{Eq. (20), p. 16}$$

Author's Comment. While defined as average values in the paper, E_{do} and E_d are evidently used as either average or maximum values. An example of use of E_{do} as a maximum value is in Equation (15):

$$(KVA)_{LV} = \frac{E_{do} I_s}{\cos a}$$

E_d is similarly used in Equation (16):

$$P = E_d I_s$$

There is some question concerning Equation (20). A suggestion is:

$$(PF)_{LV} = \frac{R}{\sqrt{R^2 + \left(\frac{3X_{pp}}{4\pi N^2}\right)^2}} \cos a$$

A minor error occurs in the nomenclature of the paper, where symbols for average and maximum power, p and P, are interchanged.

Discussion by C. N. Clark

Utility engineers are greatly interested in the development of the frequency-changer welders because of the possibilities offered for reduction in kva. demand, improvement in power factor and balancing of load between the three phases of the power system, as compared with the usual load characteristics found in the conventional single-phase welder.

It must be recognized, of course, that where the capacity of the power supply system is adequate for the required single-phase welder, as in many existing large industrial plants, it would be difficult to justify the use of a frequency-changer welder because of its higher initial cost. Its selection instead of a single-phase welder would in such cases have to be based primarily on welding advantages.

Where it would be necessary to make a major change in the existing power supply or to bring in an entirely new supply such as a new higher voltage circuit with associated equipment to supply a single-phase welder, it would be desirable to compare the total cost of the welder and the power supply against the corresponding costs using a frequency-changer welder.

In several recent cases where Duquesne Light Co. engineers have investigated the relative costs of supplying power to comparable single-phase welders and frequency-changer welders for specific operations, it has been found that the frequency-changer welder could be served from the existing three-phase power service with only minor changes, whereas the single-phase welder required costly extensions or reinforcements.

The information in Mr. Boice's paper will be very useful to the power companies in their determination of requirements for service to frequency-changer welders. A better understanding of their characteristics will

C. N. Clark is Distribution Engineer, Duquesne Light Co., Pittsburgh, Pa.

(*Continued on page 149*)

* See author's comment at the end of this discussion.

WELDING METALLURGY—Iron and Steel

The Society has revised the Welding Metallurgy book originally published in 1940. The book has been brought up to date and a wealth of new material added. This book is being reproduced serially in* The Welding Journal. *Copies in attractive imitation leather covers are available at $2.50

by O. H. Henry, G. E. Claussen and G. E. Linnert

Chapter 6
THE MECHANICAL PROPERTIES OF METALS

Metals are strong because they support considerable load without deforming appreciably. Liquids will support loads too—for example, iron will float on mercury—but not without large-scale displacement. When a load is placed on a metal crystal, atoms move closer together in the direction of the load, and spread apart at right angles to the load. The movement of the atoms at first is extremely small. A 1-inch cube of tool steel, for instance, will be compressed only 0.001 inch by a load of 30,000 pounds. When the load is removed, the cube recovers its original dimensions. For this reason, metal crystals are said to be elastic.

A metal recovers its original shape when a load below its elastic limit is removed, for the reason that atoms of a metal below the freezing point or melting point interact so as to be neither closer together nor farther apart than a critical distance related to the lattice spacing. Two metal atoms in a crystal are attracted toward each other by a gravitational or field effect (two masses attract each other). But when the electron shells of the two atoms interpenetrate, the positive nuclei of the atoms exert a repulsive force. The equilibrium between the attractive and repulsive forces (interatomic bonds) establishes the distance between atoms. When we apply a load to metal we are disturbing the equilibrium between the interatomic forces and there is an ensuing adjustment of interatomic spacing. We do not have much control over interatomic bonds, for it is known that if the interatomic forces potentially in the metals were utilized fully, the strength of metals would be many times as high as it is.

Picture a metal, for the moment, as a string of atoms When tension is put on the string, the atoms move apart. If the load exceeds the limit of elastic behavior, the atoms remain apart. Beyond a critical load the string fails, Fig. 30.

The crystal, however, is not one string of atoms; it is a bundle of millions of strings, each atom in one string attracted as much to neighbors in another string as to neighbors above and below it in its own string, as shown in Fig. 31.

Fig. 30—Single Strings of Atoms Under Stress

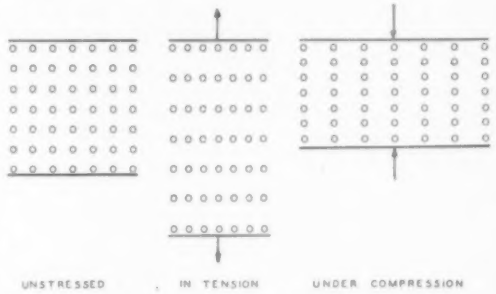


Fig. 31—Group of Planes of Atoms Under Elastic Stress

The diagram shows on an exaggerated scale that the atoms move apart in the direction of elastic tension and together in the direction of elastic compression before slip begins

These schematic diagrams fail to place the crystal in its true light, for the strings are better represented by planes, and the planes may be at many angles to the load Fig. 32. As we have seen, the important planes—the planes most favorable for slip—are the planes that are

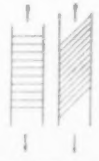


Fig. 32—Slip Planes at Different Angles to the Load

The planes at the right are more favorable for slip than the planes at the left. Only one set of slip planes is shown; face-centered cubic crystals have four sets of equivalent slip planes. In iron at room temperature slip may occur on several types of planes, depending upon which type is in the most favorable position. Slip bands in iron often are forked, irregular, or wavy, and are apparently unrelated to any principal plan

O. H. Henry is Professor of Metallurgical Engineering, Polytechnic Institute of Brooklyn. **G. E. Claussen** formerly was Adjunct Professor of Metallurgy, Polytechnic Institute of Brooklyn, now, Metallurgist, Reid-Avery Co., Baltimore, Maryland. **G. E. Linnert,** who revised the second edition, is Senior Research Engineer, Armco Steel Corporation, Baltimore, Md.

farthest apart. A moment's reflection will make it clear that the planes that are farthest apart are the planes containing the densest population of atoms.

The planes of a crystal may fail under load in two ways, Fig. 33: first, by slip—the planes move parallel to each other; and second, by rupture—the planes pull apart.

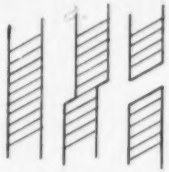


Fig. 33—The Crystal in the Center Has Adjusted Itself to Load Through Slip and Strain Hardening on One Plane. The Crystal on the Right Has Fractured Under Load with Little Deformation

In most metal crystals slip occurs long before rupture. Slip occurs when the load has been increased to such an extent that the atoms no longer can behave elastically; in other words, the elastic limit has been exceeded. Slip is permanent deformation. When the load is removed the crystals or grains will be found to have changed in shape. The plane upon which slip has occurred can easily be seen by examining the crystal. The slip plane appears as a line on the surface. Once slip has occurred on a plane, that plane is strengthened and further slip is forced to occur on another plane.

Slip occurred on the first plane because there are deviations from the ideal lattice structure in every crystal. The deviations seem to be associated with impurities. After the atoms on a slip plane have been moved simultaneously across the potential barrier due to atoms in the adjacent plane, the crystal has been permanently deformed. During the movement of planes of atoms over each other there are obscure occurrences, perhaps local bending of the planes which lock the planes together and force them out of action. The load on the crystal must be increased to cause slip to occur on another plane, which often is at a characteristic and small distance from the first plane of slip.

The increase in load required to bring successive slip planes into action is the origin of work hardening or strain hardening—the hardening of a metal when we cold work it. Eventually so many planes of the crystal have undergone slip, with attendant disturbance in the vicinity of every slip plane, that capacity for slip is exhausted and rupture ensues upon further increasing the load.

The planes upon which slip occurs are visible under the microscope if the polished specimen is examined after plastic deformation but without repolishing. The steps on the surface shown in Fig. 33 are visible. If the specimen is repolished the steps disappear but, because the metal in the immediate vicinity of slip is strain hardened, planes upon which slip has occurred appear in relief. Etching attacks the slip planes, in general, more deeply than unslipped metal and therefore reveals them.

Rupture is a complicated phenomenon and is not to be explained as simply as we have done. The first effect of load is to cause elastic deformation, which is recovered as the load is removed. Beyond the elastic limit, permanent deformation occurs and is called plastic (inelastic) deformation. In addition to slip planes, permanent deformation of a crystal may create *twins*, Fig. 34, particularly in Armco iron subjected to hammer blows at room temperature. Twinning occurs in gamma iron as a result of hot forging. When alpha iron changes to gamma iron as the temperature rises through 1670° F twins are

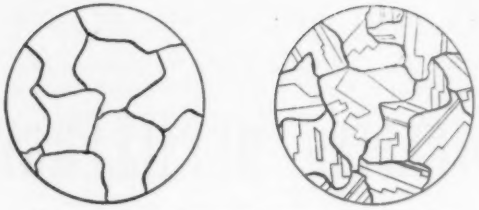


Fig. 34—Untwinned Grains (Left) and Twinned Grains (Right)

formed in the new grains of gamma. Twins are of the same composition and crystal structure as the remainder of the grain, but the crystal planes in the twinned portion are simply rotated through an angle with respect to the remainder of the grain.

During slip, large blocks of crystal slide over each other but do not change their relative orientation in so doing. In twinning the orientation is changed. The operation of twinning may be visualized in Fig. 35. So far as is known, twinning occurs generally to facilitate slip by rotating a part of the crystal so that slip planes are at a more favorable angle than those already functioning.

In truth the phrase "twinned portion of a grain" is ambiguous. Several parts of the same grain may have undergone twinning and it is impossible to state which part rotated and which part did not. Besides mechanical twins and transition twins, twins occur in some metals, such as copper and nickel, as a result of recrystallization following cold work, and in some materials during crystallization from the melt. Twins in gamma iron arise

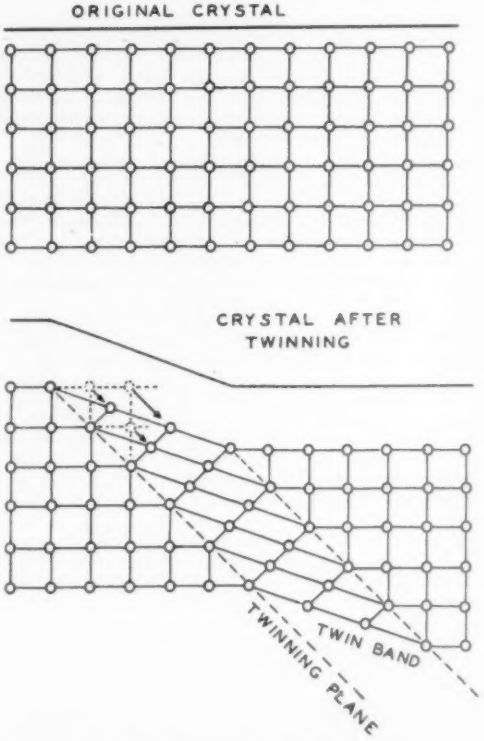


Fig. 35—Twinning in a Metal Crystal

from transition or from recrystallization (annealing) after cold work. Twins are rarely seen in alpha iron, but may be caused by a sudden blow.

Metals in commercial use always consists of a large number of crystals. Under load each crystal attempts to behave as if it were a free individual but is hampered by adjacent crystals, to a less extent if the crystal is on the surface of the part.

Grain boundaries obstruct slip, not because there is any film of metal in a mysterious condition acting as a cement at the grain boundaries, but because the crystal lattices in adjacent crystals are tilted with respect to each other. The angle between the lattices of adjacent crystals governs the obstruction to slip. The greater the angle, the greater is the obstruction to slip, in general. If lattices of adjacent crystals have nearly the same orientation, the grain boundary has a negligible effect on slip and strength. The region affected by the boundary is confined to a narrow band close to the boundary. Hence, fine-grained metal with a greater area of grain boundaries than coarse-grained metal has a greater proportion of material affected by the grain boundaries, from which may arise the greater hardness customarily observed in fine-grained metal compared with coarse-grained.

Summarizing, we find that a metal under load may change dimensions temporarily (elastic strain) or permanently (plastic or inelastic deformation). Elastic deformation leaves no trace, whereas plastic deformation causes planes of atoms to slip over each other. Near grain boundaries the slip may be different in character from slip well within the boundaries depending upon the inclination of the adjoining crystal lattices.

To predict the reaction of each crystal of a metal to inelastic deformation is impossible at present, but the conceptions of slip and rupture are none the less useful in comprehending the nature of such processes as peening, cold work, and failure under service loads.

PROPERTIES OF STEEL

Under a steady load, called a static load, steel deforms in accordance with *Hooke's law* (strain proportional to stress) up to the elastic limit. The ratio of the stress to the elastic strain is called the modulus of elasticity, or *Young's modulus*. For iron or steel, the modulus of elasticity is approx. 30,000,000 psi (with the stress in psi and strain in inches per inch, a load of 3000 psi produces an elastic strain of 0.0001 inch). Very little change can be effected in the modulus of elasticity by heat treating or alloying. The modulus of elasticity for aluminum and aluminum alloys is 10,300,000, for copper and its alloys 15,000,000, and for magnesium and its alloys 6,500,000. The modulus of elasticity must often receive serious consideration in designing metal structures, and the foregoing data point out an advantage of using steel.

Strength

A number of terms frequently used in expressing the strength of steel are given below:

Stress—Load divided by original cross-sectional area, expressed in pounds per square inch (psi).

Strain—Change in dimension per unit dimension, for example, inches per inch, or percent in a stated length, usually 2 or 8 inches.

Elastic Limit—The greatest stress which the steel can withstand without exhibiting permanent deformation when the stress is released.

Yield Strength—Beyond the elastic limit, steel undergoes permanent strain. A rough *yield point* may be determined at which the steel produces a marked increase in strain with little or no increase in load. The *yield strength* is usually expressed as the amount of stress to produce a specific degree of permanent strain, commonly specified as 0.2 percent. When the steel is permanently deformed 0.002 inch per inch of length, the yield strength is said to be reached.

Ultimate (Tensile) Strength—The maximum tensile stress, computed on the original cross-section, which the steel can withstand.

Ductility

The amount of permanent deformation which a steel undergoes during the static tensile test, which usually is made on cylindrical specimens having an effective length of 2 or 8 inches and 0.505- or 0.800-inch diameter, is the measure of ductility. Usually only the elongation of the fractured specimen is measured but the reduction of the area at the necked section may be determined, too.

Elongation—The two parts of the broken specimen are fitted together. The distance between the two punch marks, initially 2 or 8 inches apart, is measured. The ratio of the increase in length divided by the original length is expressed as a percentage of the original length. A ductile low-carbon steel may have 30 percent elongation in 2 inches, for instance.

Reduction of Area—As in the determination of elongation, the decrease in cross-sectional area, computed from change in diameter, is expressed as a percentage of the original cross-sectional area. For example, ductile mild steel might exhibit 50 percent reduction of area.

Bend Ductility

After the specimen is bent to a specified extent, such as 180°, the elongation of the tension (outer) surface is measured in the same way as the elongation in the tension test.

Hardness

Brinell Hardness—This type of hardness determination is made by applying a load of 3000 kg for 30 seconds on a hard steel ball 10 mm in diameter resting on the smooth surface of the steel to be tested. The diameter of the impression made by the ball is measured, from which the Brinell number is determined by means of a formula. A chart giving the Brinell numbers for the impression diameters is nearly always used.

Vickers Hardness—This type of hardness test is similar to Brinell except that a diamond pyramid is used instead of a ball.

Rockwell Hardness—In this test, the hardness number is inversely proportional to the depth of the indentation produced by a hard steel ball $^1/_{16}$ inch in diameter under a load of 100 kg (B scale), or by a diamond cone under a load of 150 kg (C scale).

Scratch Hardness—The resistance of the surface to scratching with a sharp hard scribe is compared with a set of known standards.

Notch Impact Value

Fracture under heavy loads often originates in service at the base of a sharp fillet or notch. The resistance of the steel to the start and propagation of a crack at the base of a standardized notch is measured by the amount of energy absorbed by the specimen as it fractures under a hammer blow delivered by a standard pendulum. The notch impact value is usually expressed in foot-pounds (ft-lb). We have two commonly used notched-bar impact test specimens, the Izod design which contains a 45° V notch, and the Charpy design which contains a special notch of the keyhole type. In general, the Izod V notch imposes a more severe notch effect upon the steel.

The notch impact value is a measure of the notch brittleness or, conversely, notch toughness. Sometimes the values are interpreted as indicating the behavior of a steel under shock loading. This may be warranted in some cases, but actually the behavior will depend greatly upon the geometry of the structure or article, the way in which the structure restrains the plastic flow of the material under rapid loading, and the ability of the material to deform plastically during rapid loading.

Typical Mechanical Properties of Different Steels

Steel	Ultimate Tensile Strength, Psi	Elongation % in 2 in.	Hardness Brinell	Hardness Rockwell	Charpy Notch Impact Value Ft-Lb
Mild Steel (as hot rolled)	55,000	30	110	B 65	20
Medium-Carbon (heat treated)	100,000	10	200	B 94	10
High-Carbon Tool Steel	250,000	1	600	C 60	1
18–8 Stainless Steel	90,000	55	160	B 85	50

Fatigue Strength

The highest stress which can be resisted by a steel without failure decreases with the increase in the number of times the stress is repeated. The *fatigue strength* is the maximum stress so determined for a stated number of repetitions, for example, 2 million. As the number of repetitions of stress is increased, the decrease in the fatigue strength brought about by the increased number of repetitions becomes smaller, until, beyond 10 million cycles for polished steel in air, the fatigue strength no longer decreases. The endurance limit of polished steel is 40 to 60 percent of its tensile strength.

FACTORS INFLUENCING THE PROPERTIES OF METALS

The structures which we fabricate by welding sometimes exhibit entirely unexpected and unpredictable mechanical behavior; at least, this appears to be so judging from the results of mechanical tests which we possibly carried out previously on laboratory type specimens. Strong, ductile metal may suddenly break with a brittle-appearing fracture, or a part designed to have an adequate factor of safety may break at the edge of a weld. Often we find that in service the metal part has been subjected to circumstances or conditions which could not be included in the laboratory testing procedure, or which were dismissed as being trivial. In the following paragraphs we will attempt to bring forth some of the variables which significantly affect the mechanical properties of metals.

Effect of Temperature

During welding the temperature of the metal at the joint rises to the melting point and falls again. All the while, if the parts are restrained, the heated metal is being subjected to complex stresses. Whether the metal fails (cracks) or distorts badly under the shrinkage stresses depends upon the magnitude and type of stresses for one thing, but also the mechanical properties of the metal at elevated temperatures.

Our intuition might tell us that as the temperature is raised the atoms become freer to move. Consequently, strength should decrease and ductility should increase. In general, our intuition would be correct, but Fig. 36 shows that there are exceptions to the rule. Beyond the recrystallization temperature the strength usually is low and at higher temperatures becomes still lower, perhaps because the crystals have lost their elastic characteristics. That is to say, small loads cause permanent deformation, which may continue for long periods of time and may end in rupture. The metal *creeps;* it continues to deform although the load is maintained constant. At room temperature the elastic deformation of steel, when a load is applied, is complete as soon as the load, which is applied to one end of the specimen, has been transmitted to the other end, a matter of a fraction of a second. At temperatures of 900° F and above, small stresses cause movements (deformation) of the specimen which continue indefinitely.

Although the strength decreases as the temperature is

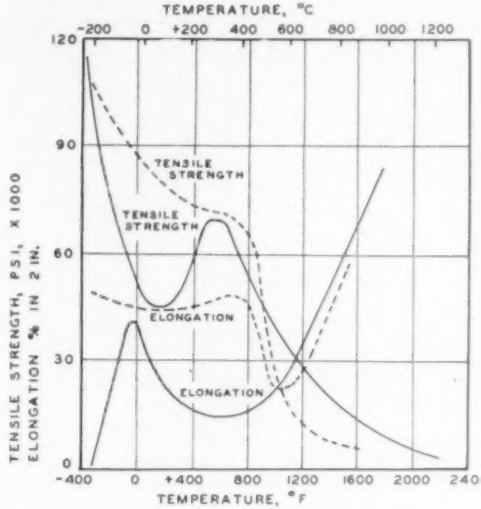


Fig. 36—Change of Tensile Strength and Elongation with Temperature

——————— Iron (annealed)

- - - - - - - - - - - - Alloy of 68 Percent Ni, 29 Percent Cu, 1.5 Percent Fe, 1.5 Percent Mn (annealed)

The results are approximate and depend upon the speed of testing, grain size, and composition of metal. The notch impact value of iron drops sharply to nearly zero at about 32° F, it rises to a maximum at 200° F, and with further increase in temperature drops slowly again

raised, the ductility may or may not increase. A few metals exhibit brittleness in characteristic temperature ranges, for example, high-sulphur steel at about 2000° F, Monel metal above 1400° F. Brittleness at elevated temperatures (red heat) generally is called *red shortness.* The usual cause of red shortness is the melting of a small portion of the metal, while the remainder is solid. The molten portion surrounds the individual grains, which lose coherence, and the metal breaks or cracks in brittle fashion. Attack of oxidizing gases or external molten metals along grain boundaries creates similar brittleness.

A steel may exhibit a condition known as *secondary brittleness.* Steels of all carbon contents seem afflicted with it. The elongation in a short-time tensile test is a little lower at 900° F, the temperature of secondary brittleness, than at temperatures somewhat higher or lower. Corresponding with the decrease in ductility there is an increase in tensile strength. The changes are on a small scale and they appear to be of no great significance to welds.

Another phenomenon similar to secondary brittleness is called *blue brittleness.* Steel in the temperature range of 400° to 700° F may exhibit reduced ductility, or when the steel is worked (hammered or bent) in this temperature range it may be found brittle upon cooling to room temperature. Again the reduction in ductility is accom-

panied by an increase in strength. So far as experience extends, blue brittleness has no significance for welding. Both secondary brittleness and blue brittleness are believed to be brought about by the precipitation of compounds of some sort, as yet unknown, in the grains of which the steel is composed.

Now let us observe what happens to the properties of metals when the temperature moves in the opposite direction, that is, toward sub-zero levels. The properties at low temperatures, even as low as —300 F, are of more than casual interest to us for now we must weld pressure vessels and other pieces of equipment which are expected to operate satisfactorily at these sub-zero temperatures in the dewaxing of petroleum, liquefaction and storage of natural gas, and so forth.

With lower temperatures, the tensile strengths of metals tend to increase; a very small increase in some metals and a significant increase in others. Changes in the ductility and toughness of the metals give us more cause for concern, however, for the ordinary steels and certain other metals become brittle as the temperature is lowered. Strangely enough, the brittleness does not appear gradually as the temperature is lowered, but instead, the metal passes through a range of temperatures over which a transition from the tough, ductile condition to a brittle condition takes place. The approximate level of the range of transition temperatures varies with different materials, and appears dependent upon their composition, structural condition, and a number of other factors not too clearly recognized. The transition range is more clearly indicated by mechanical tests which readily reveal any inability on the part of the metal to deform plastically. The Izod and Charpy notched-bar impact tests, with their notches and shock loading, are usually the first to show up lack of toughness as the metal is subjected to tests at progressively lower temperatures. Fortunately, some metals do not display this alarming lack of toughness at low temperatures. These are metals with the face-centered cubic type of crystalline structure, like aluminum, copper, and steels possessing the austenitic microstructure(for example, austenitic Cr-Ni stainless steels).

Effect of Velocity

The speed with which a blow is delivered may have some effect on the resistance of a metal to deformation and rupture. There should be no confusion about mass, speed, and energy. Remember that a body struck absorbs the energy of the body striking it, or only part of the energy if the body delivering the blow is not stopped, for example a bullet passing through a sheet of paper. To the body being struck, it is immaterial, to consider a numerical example, whether the blow is delivered by a 100-pound weight falling 10 feet or a 1000-pound weight falling 1 foot. Both deliver the same energy, 1000 ft-lb, although the speed at which the lighter body hits is greater than the speed of the heavier body. Beyond a critical speed, which varies from 40 to 400 feet per second for different metals, a metal loses some of its capacity to absorb energy. Bodies traveling at extremely high speed, such as turbine disks, absorb less energy before rupture ensues than the same body traveling at a speed below the critical.

Effect of Multiaxial Stresses

When a metal is stressed below the elastic limit in one direction, for example in simple tension, we say that a *uniaxial* stress has been applied. In this case, the metal undergoes elastic strain in proportion to the load applied (Hooke's law) and the amount of strain can be calculated from Young's modulus. At the same time that this elastic elongation occurs, the cross section diminishes. This is not altogether surprising, but it is important to know that a ratio exists between the increase in length and the decrease in cross section, known as *Poisson's ratio*. The ratio of the relative decrease of diameter in a round bar to the unit increase in length is about 1/4 for most metals. For steel, Poisson's ratio is about 0.27. This ratio applies to compressive as well as tensile stresses.

Now let us picture an instance where first a tension stress below the elastic limit is applied to a metal section. According to Hooke's law the metal should elongate, and following Poisson's ratio the cross section should diminish. Second, let us assume that in this instance another tension stress is applied to the section at right angles to the direction of the initial stress thus setting up *biaxial* stress conditions. It is not difficult to see that if the biaxial tension stresses are raised above the elastic limit, the plastic deformation of the section would be seriously impeded. If a third tension stress were added to the picture to cause *triaxial* stresses, the circumstances under which plastic flow must occur are obviously even more complex. When metals are loaded under *multiaxial* stresses, they are apt to exhibit abnormally low ductility, and at times fail at abnormally low loads.

Effect of Notches

The stress at the base of a notch, Fig. 37, is higher than that calculated with the aid of design formulas. As a coarse approximation the stress at the base of a notch may be two or three times the stress expected from design calculation; that is, the stress concentration factor of a notch may be 2 to 3. The precise value depends upon the shape of the notch; the sharper the notch, the higher the stress concentration. The notch impact specimen is struck by a moving pendulum for the sake of simplicity, and precisely the same energy should be absorbed in rupturing the notched specimen if the load were applied slowly. However, this may not always be true for the

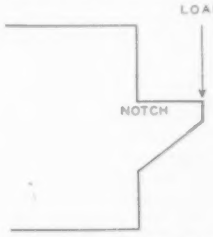


Fig. 37—Notch in Structure Under Load

notch introduces still another factor—that of multiaxial stresses, which may vary in its effect depending upon the nature of the metal and the speed of testing.

To explain the origin of multiaxial stresses in a notched-bar specimen during testing, we can picture the metal along the sides of the notch acting to restrain any lateral contraction of the metal at the base of the notch. When the specimen is struck a blow from a direction normal to the length of the notch, longitudinal tension stress is raised in the metal at the base of the notch which in turn demands that some lateral contraction take place in the specimen at this point. Since lateral contraction is hindered by the metal above the notch, a transverse stress appears in the specimen to form biaxial stresses at the base of the notch. Under biaxial stress conditions plastic flow cannot take place in the normal manner and a rupture is likely to occur prematurely. Obviously, the formation of a rupture or crack at an early moment will result in poor energy absorption.

Anyone familiar with metals realizes the ominous sig-

nificance of the term crack. As a load is applied to a notched-bar specimen, Fig. 38, the crystals at the base of the notch are subjected first to elastic stress, then to permanent (inelastic) deformation. At some stage a crack may start, which indicates that the planes available for slip in the most highly stressed crystal near the notch have been used up. The crack is equivalent to an extremely sharp notch, and complete rupture occurs shortly after the crack starts.

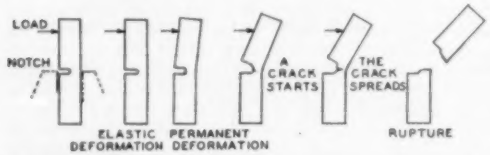


Fig. 39—Stages in the Fracture of a Notched Impact Specimen. The Lower Half of the Specimen Is Gripped Rigidly in a Vise

If a notch exists in a structure which is subjected to repeated loads, fatigue failure is very likely to occur at the base of the notch, usually at unexpectedly low loads because of the stress-concentration factor.

Effect of Grain Size

Grain size is important not so much for strength, which is not greatly affected, as for ductility. As a rule, the ductility of a metal decreases as the grain size increases. Coarse-grained metals are softer and less ductile than fine-grained. The explanation is thought to lie in the grain boundaries. The path of slip must change in direction in crossing from one crystal to an adjacent one in which the crystal planes are differently inclined (differently oriented). The more frequently slip must change direction, the more fully will the slip planes in each crystal be utilized, for the deformation will be uniform rather than localized in the few crystals whose slip planes happen to be most favorably inclined to the load. The effect is readily demonstrated by the crinkled appearance along the bend of a coarse-grained sheet compared with a fine-grained sheet.

The altering of grain size will be explained in more detail in Chapter 11 in a discussion on heat treatment. At the present we may state that the grain size is smaller the lower the temperature of full annealing or normalizing, and the greater the degree of cold work prior to annealing. Fine-grained metal is particularly resistant to failure at a notch; fine grains resist the spread of a crack, especially at sub-zero temperatures. We will see that multi-layer welds are fine grained and have remarkably good notch impact value.

Fig. 39—(Upper Diagram) Brittle Fracture: No Slip. (Lower Diagram Ductile Fracture: Slip (Cup and Cone Type of Tensile Fracture)

FRACTURES IN METALS

Metals break apart in two ways; by brittle fracture and by ductile fracture, Fig. 39. Fracture has the same meaning as rupture, and both signify separation of a metal into two or more parts under stress.

Let us see what happens to a metal as stress is applied. First the metal behaves in an elastic manner, that is, the atoms retain their positions but move very slightly apart in the direction of tension and very slightly together in the direction of compression. After the elastic limit is passed blocks of atoms slip along slip planes, which has the effect of cold work and permits the metal to withstand higher stresses. Slip involves yielding and deformation; in other words, a metal whose crystals can slip a great deal is ductile.

If the planes of a crystal for some reason cannot slip, the planes of atoms, instead of slipping over each other, move further and further apart. The distance that the planes of atoms can move apart before they lose coherence is extremely small. Consequently, when the small allowable distance is exceeded the metal has fractured in a brittle manner because the deformation has been scarcely measurable. Brittle fractures are sometimes referred to as *cleavage* fractures.

Ductile fractures, Fig. 40, have a different appearance from brittle fractures. Ductile fractures have a silky appearance suggestive of the two surfaces of the fracture having been rubbed (slipped) on each other. They often appear to have failed mainly by shear. Sometimes a fracture has both ductile and brittle portions, the brittle portion being at the center of the fracture where the crystals have been most constrained by surrounding metal. A curious combination of ductile and brittle fractures can be found in tensile and bend specimens of weld metal deposited by organic coated electrodes. Tiny zones of brittle failure in an otherwise ductile fracture appear, which we call *fisheyes*. Their cause is discussed in Chapter 13.

Effect of Temperature on Fractures

Temperature may influence the character of a fracture in metals. We have already discussed the fact that at sub-zero temperatures some metals, unfortunately this includes ordinary iron and steel, pass through a transition range over which a rather marked tendency toward brittleness appears. The temperature level at which we detect this range is no doubt inherent with each particular lot of metal, but is also determined by the type and design of test specimen employed. Notched specimens, possibly tensile, bend, impact, or fatigue type, are favored for determining the transition range. We may look for an energy-transition range, where a sudden decrease occurs in tensile strength or impact value, or we may seek a fracture-transition range where the fractured faces of the broken specimen change from the silky, ductile shear type to the brittle, cleavage type.

As the temperature is raised above room temperature most metals become more ductile although some become brittle. Apart from the effect of temperature on the abil-

Fig. 40—(Left) Shear Fracture in Aluminum Strip. (Right) Ductile Fracture in Steel Strip

ity of the crystal planes to slip on each other, there is generally a change in type of fracture at a temperature corresponding to recrystallization. Below the recrystallization temperature the path of fracture lies through the grains. Above the recrystallization temperature, the

path of fracture is along the grain boundaries. Sometimes the recrystallization temperature is called the *equicohesive temperature*, for it is the temperature at which the grain boundaries appear to have the same strength as the grains. For a given material the recrystallization temperature is not constant, in the sense that the melting point is constant. The higher the degree of cold work and the longer the duration of heating, the lower is the temperature at which the metal will recrystallize.

From what we know of slip planes and recrystallization, it is easy to understand the effect of temperature in changing the type of fracture, Fig. 41. Below the recrystallization temperature, slip planes are formed under stress. The slip planes extend to the boundaries of the grains which secure a toothed appearance through having been intersected by innumerable slip planes. Consequently, fracture occurs along the weakest of the slip planes (transgranular). Above the recrystallization temperature, slip planes cause immediate recrystallization, and fracture follows the grain boundaries. The condition of the crystals at grain boundaries is stronger than the crystal planes below the recrystallization temperature, but weaker above it.

Fig. 41—Three Types of Tension Fracture

(Left) Intergranular fracture at room temperature, possibly caused by caustic embrittlement. There is rarely any deformation in intergranular fractures at room temperature, but at temperatures above the recrystallization temperature there is deformation, yet the fracture is intergranular and the grains have recrystallized

(Middle) Brittle transgranular fracture at room temperature. There has been practically no deformation of the grains

(Right) Ductile transgranular fracture at room temperature. The grains have undergone a great deal of deformation

The intergranular type of fracture has an entirely different appearance from the transgranular. If the two parts of an intergranular fracture are matched together and examined as a polished section under the microscope, the grains of the two parts will be found to fit perfectly and to have separated along the grain boundaries. Examination of a transgranular fracture, on the contrary, nearly always reveals distorted grains which have separated along slip planes, not along grain boundaries. The difference in appearance permits us to state whether a fracture has occurred at high or low temperatures, which often is important in examining fractured welds. The surface of a high-temperature fracture in steel, which extends to the surface and allows air to enter the fissure, usually appears brown or blue due to the formation of temper colors.

Occasionally intergranular failure occurs in steel at room temperature. Extremely hard and coarse-grained tool steel may fracture along the grain boundaries at room temperature. Mild steel that has been attacked under stress by some corrosive agents or molten metals (solders or brazing alloys) also fractures along the grain boundaries. Such fractures occur without measurable deformation.

Effect of Type of Stress

Each type of stress—tension, compression, torsion, bending, etc.—creates a characteristic type of fracture, which changes with different materials and with different sizes and shapes of parts. There is one important type of stress, however, which produces a fracture that is easy to recognize. That type of stress is fatigue.

As an example of fatigue fracture, consider the bolt in Fig. 42, which is being stressed back and forth continually in service. After the bolt has received a large number of repetitions of service loads of varying magnitude, its fatigue strength is exceeded and a tiny crack starts at the most highly stressed sides *A* and *B*. The crack acts as a stress raiser and succeeding applications of load extend the crack. During each repetition the surfaces of the crack rub on each other. Hence arise the two characteristic features of the fatigue failure fracture: (1) the

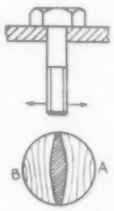


Fig. 42—Fatigue Fracture of Bolt

Fracture may have occurred under head or in threads, depending on conditions. Crack starts at the most highly stressed regions *A* and *B*. The lower view shows the fracture slightly enlarged. The light lines show the gradual extension inward of the crack. The shaded area of the fracture may exhibit crystal facets, often seen in fractures of tensile test specimens. The term *crystallization* should never be used to describe fatigue fractures

smooth, rubbed surfaces, and (2) the lines, similar to tide lines on a beach, showing the gradual progress of the crack. The crack has spread to such an extent that the remaining cross section of metal no longer is able to withstand the static load. Static fracture then ensues over the remaining cross section. Whether the steel is ductile or brittle there is practically no deformation in the vicinity of a fatigue fracture, which is transgranular, like most other types of fracture in steel at room temperature.

BRITTLENESS IN METALS

What is *brittleness?* A brittle weld fractures without deformation. To illustrate brittleness and its opposites, bend $^1/_8$-inch rods of glass, soft rubber, lead, and soft steel. The glass rod snaps; it behaves in a brittle fashion. The soft rubber rod can be bent double, but springs back to its original shape; it is elastic. The lead rod is bent double easily and remains bent; it is weak and ductile. Likewise, the soft steel rod can be bent double and remains bent, but it requires more force to bend the steel than the lead. Compared with lead, the soft steel is tough as well as ductile. Yet the three materials that can be bent easily at room temperature can be made to break in a brittle fashion under some condition, while the glass rod if bent at a red heat, does not snap, but behaves like taffy.

Although we have no difficulty in stating that, in bending, glass is brittle and lead is not at room temperature, it is more difficult to decide whether or not different steels are brittle. In the tensile test with load in one direction, an elongation at fracture of 20 percent in 2 inches is characteristic of ductile weld metal; 5 percent would be brittle. Yet bridge wire with 5 per cent elongation is ductile, while with 2 percent it would be classed as brittle. We see that there is no absolute value of tensile ductility below which all materials can be said to be brittle and above which they can be said to be not brittle. For purposes of discussion, however, we can say that a material is brittle if it breaks without appreciable deformation, Fig. 43.

It is disconcerting to find that a metal which deforms greatly before fracture when the tensile load is applied in one direction, does not deform to so great an extent if tensile stress is applied to the metal in two directions at

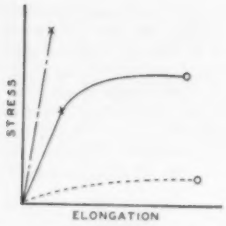


Fig. 43—Stress-Strain Diagrams in the Tensile Test

If fracture occurs at *X* before the specimen has elongated permanently to any appreciable extent, it is said to be in the "brittle" condition. Metal deforming considerably before fracture at *O* is said to be ductile, regardless of the magnitude of stress at fracture

right angles, as in the shell of a boiler, Fig. 44. The steam inside the boiler tends to blow off the ends. They are held to the shell because the steel can withstand the tensile stress *A-A* without failure. The steam also tends to expand the diameter of the shell, which causes tensile stress *B-B* at right angles to *A-A*. When the shell at last ruptures under excessive steam pressure, we examine the fracture, and find that there has been little deformation, not more than 2 to 5 percent. Yet a specimen cut

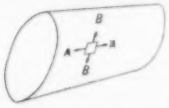


Fig. 44—Stress Acts in Two Directions in a Closed Drum Under Internal Pressure

from the shell develops an elongation in the tension test of 20 percent. The decrease in elongation when the two tensile stresses are applied at right angles to each other suggests that the steel cannot contract to so great an extent as it does when tensile stress is applied in only one direction. If the second stress is compressive, instead of tensile, the contraction of the steel under the tensile load is favored, with the result that the deformation is unusually large before fracture occurs. If tensile stresses in two directions reduce the deformation which a material can undergo before fracture, Fig. 45, tensile stresses in three directions still further reduce the deformation. This is a practical example of the influence of multiaxial stresses which we discussed earlier in this part.

The embrittling effect of notches in a metal, as we have also stated earlier, is caused by the biaxial and triaxial tensile stresses generally created in their vicinity on the

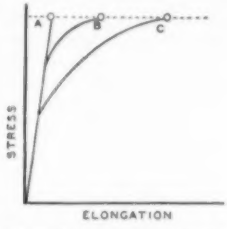


Fig. 45—Effect of Multiaxial Tensile Stress on Elongation at Fracture (Schematic)

O = Fracture
A = Tensile stress in three directions
B = Tensile stress in two directions
C = Tensile stress in one direction

application of a load. Comparing Fig. 45 with Fig. 43, we see that a mild steel which behaves in a brittle fashion when tensile stress is applied in three directions may behave as a ductile material in the tensile test with load in only one direction. Why cannot the steel deform so much when tensile stress is in two directions? The answer is to be found in the process of slip along crystal planes by which metals deform. When equal tensile stresses act in three directions at right angles at once—a condition which rarely occurs—slip is prevented completely, because no plane of atoms is able to move in the opposite direction from the plane above or below it. When slip is prevented from occurring, the material fractures by one plane of atoms losing its grip on an adjacent plane.

Five Ways to Prevent Slip

Brittleness thus becomes a question of slip. We have seen that slip may be prevented by biaxial or triaxial tensile stress. There are four other ways of preventing slip.

The first way to prevent slip is absurdly simple. Test a material in which slip has been forced to occur previously on every possible slip plane, for example, by cold working (cold rolling, cold hammering, etc.). When tensile stress is applied, no planes can slip and the metal can undergo no permanent deformation before brittle fracture. Brittle welds from this source sometimes are found in forge-welded wrought iron. The smith knows that he should continue to hammer the weld below a white heat to refine the grain size. If, however, he carelessly hammers the weld at too low temperature, he cold works the metal and reduces its capacity for subsequent deformation.

Slip can also be prevented by wedges inserted at intervals along the planes of atoms. Like emery between polished gage blocks, the wedges prevent the planes of atoms from sliding over each other. The wedges are crystals which can be induced to grow at myriads of points in a crystal of a different sort. A good example of slip prevention by tiny crystals is martensite. When austenite is cooled so rapidly that it does not transform to pearlite, it transforms at a lower temperature to martensite, the transformation involving a change in crystal structure and appearance of extremely small crystals of carbon or iron carbide. Thus some of the planes of atoms in the austenite are jumbled into another form, this process itself tending to prevent slip. At the same time, another type of crystal, carbon or iron carbide, appears and blocks still further any slip along planes of atoms. Consequently, martensite in the higher-carbon steels at any rate provides practically no planes for slip, and fractures without appreciable deformation under load.

Martensite in the heat-affected zone of an alloy steel weld may or may not cause the joint as a whole to be brittle, Fig. 46. The stress-strain curves of the three essential parts of the joint are shown in Fig. 46(*a*). If the

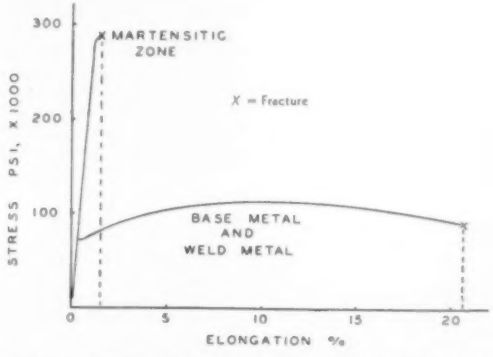


Fig. 46 (a)—Stress-Strain Diagram Showing a Ductile Base Metal (and Weld Metal) and a Brittle Heat-Affected Zone

stress is applied perpendicular to the weld, Fig. 46 (*b*), the stress cannot rise above the yield strength of the weld metal and base metal, without deformation of both. Should the stress be applied parallel to the weld, Fig. 46 (*c*), the conditions are entirely different. As the strain increases, the stress rapidly rises in the martensitic zone, corresponding to the stress-strain curve in Fig. 46 (*a*). At a small elongation the martensitic zone ruptures; that is, it cracks. Once the crack appears, it acts as a notch with the accompanying multiaxial stresses, and may spread with the velocity of a pistol shot through the remainder of the cross section.

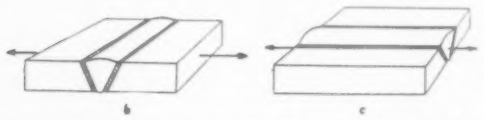


Fig. 46 (b) (Left)—Single-Layer Butt Weld Made with a Mild Steel Electrode in High-Tensile, Medium-Carbon Steel

Shaded area is martensitic heat-affected zone. When stressed transversely, as shown by the arrows, the weld metal and unaffected base metal deform without causing cracks in the shaded zone

(c) (Right)—Same as (b) but Stressed in the Direction of the Weld

The martensitic zone is forced to deform and soon cracks, as shown in (*a*)

The third basic way in which slip can be prevented is by means of films of brittle, weak material surrounding the crystal grains of another more ductile metal. We know that a sharp rap on a bathtub causes the enamel to crack without affecting the steel beneath it. What would happen if every grain of steel were surrounded by a film of enamel, which is not very different from glass or slag. Being unable to deform under stress the enamel films would crack at a very low stress. The grains of steel, having nothing to hold them together, fall apart once the cementing film has broken.

There are many examples of embrittlement of metals by weak or brittle films of impurities. Bismuth in minute percentages forms films in copper, which loses its characteristic ductility. Repeated stress annealing of welded chains produces films of cementite around the grains of ferrite and the chain becomes embrittled. Iron sulphide, being the last material to solidify in improperly refined steel castings, exists as films which reduce the ductility to extraordinarily low values.

The final way to prevent slip is to affect the basic properties of the metal so that instead of planes of atoms slipping under stress, they tend to lose their grip on each other. The situation may be visualized by sliding two gage blocks over each other. With an oil film between the blocks and perfectly plane, smooth surfaces, it is easier to move the blocks by sliding one on the other than by pulling them apart. By removing the oil film or spoiling the finish on the contacting surfaces, we can make it easier to pull the blocks apart than to cause them to slide over each other. Although similar changes in ease of sliding and pulling apart are known to be undergone by metals, we have little control over them. The changes are governed by the ratio of tensile strength to shear strength. If the ratio exceeds 2, the planes of atoms tend to pull apart without slip, and the metal fractures in a brittle fashion. An example is the embrittlement of notched mild steel weld metal at about −100° F. Steel which is tough in the presence of a notch at room temperature may break like glass below −100° F, the change in behavior being related to a strange change in ratio of tensile to shear strength.

The five ways in which brittleness may be caused in metals are: (1) multiaxial stresses (which includes notches), (2) cold work (no slip planes available), (3) precipitation (wedges in the available slip planes), (4) intergranular films which rupture before slip occurs in the grains themselves, and (5) high ratio of tensile to shear strength. We are now prepared to understand all the brittle conditions in which steel may exist, starting at the highest temperatures.

HOT WORK

We have seen that hot work is deformation imposed on the metal at temperatures at which the distorted grains instantly recrystallize (with or without twinning) to form equiaxed grains. In other words, hot work is performed above the lowest temperature at which recrystallization occurs (called the recrystallization temperature). The recrystallization temperature of low-carbon steel is about 950° F, but since there is a transformation at 1335° F in all plain-carbon steels, hot work is done above 1335° F.

The higher the temperature at which hot work is completed, the coarser will be the grain size, in accordance with the general rule that grain size increases as the temperature increases above the transformation or recrystallization temperature. Yet we know that when steel passes through the transformation at 1335° to 1670° F (depends upon carbon content) a new set of smaller grains is formed. Notwithstanding, the coarse grain established at the elevated temperature leaves its mark on the finer grains resulting during cooling through the transition temperature in the form of Widmannstätten structure (see section on the single pass weld in steel), which is not the most ductile condition. For the finest grain size, therefore, hot work should be completed at as low a temperature as possible without cold working the metal.

COLD WORK

Cold work is deformation imposed on the metal below the recrystallization temperature; for example, cold rolling a steel bar at room temperature. Milling, drilling, turning, and knurling, and, in fact, all machine and cold-forming operations cold work the metal, in contrast with oxygen cutting and oxygen machining which involve no cold work. Cold work distorts the grains, Fig. 47. Distortion increases strength but decreases the ductility. Cold-rolled steel has higher strength (calculated on the original area of the specimen) than hot-rolled steel of the same composition, because the grains in the cold-rolled steel are deformed to some extent before the tension (deformation) test is begun.

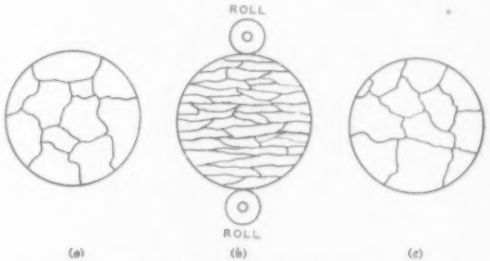


Fig. 47—(a) Iron Before Cold Rolling: Equiaxed Grains. (b) During (and After) Cold Rolling: Grains Elongate in Direction of Rolling. Compressed Perpendicular to the Direction of Rolling. (c) After Recrystallization: Equiaxed Grains

Increase in strength by cold work is accompanied by decrease in ductility, as shown in the following table.

Effect of Cold Work on Mechanical Properties of Steel Sheet

Low-Carbon Steel Sheet	Yield Strength, Psi	Tensile Strength, Psi	Elong., % in 2 In.	Rockwell Hardness
Hot-Rolled Condition.....	40,000	55,000	30	B 60
Hot Rolled, then Cold Rolled to Reduce Thickness 40%.....	85,000	85,000	4	B 90
Cold Rolled, then Recrystallized	40,000	55,000	30	B 60

PEENING

Occasionally welds are peened. If the weld is peened at a white heat the steel will be so soft that the hammer will sink deep into the weld and the grain size will not be changed greatly. If peening is done at a dull red heat (slightly above the transition temperature) the grain size will be refined greatly. Below a dull red heat, peening cold works the metal and, while increasing its strength, impairs the ductility. Cold work distorts the grains and makes the weld subject to cracking.

Peening will be most effective if the weld is at a dull red heat. However, after the welder has completed a section of the weld, the weld is hot at the end but relatively cold at the starting point. If the peening is to be done by the operator, he will probably cold work the start of the weld and hot work the hot end of the weld at too high a temperature to secure maximum grain refinement. If he can reheat the weld to the proper temperature or if a helper follows him at the proper distance with a hammer, peening can be done at the correct temperature, if at a considerable expense.

We have assumed thus far that only weld metal is to be peened. However, consider the steel next to the weld; that is, the heat-affected zone. It has been heated to temperatures up to the melting point depending on the distance from the puddle. Obeying the well-known laws, the grains in the heat-affected zone that have passed through the recrystallization and transition temperatures will be refined. The grains nearer the weld have been heated to a higher temperature and are coarsened, Fig.48.

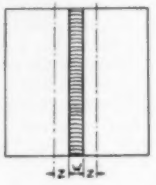


Fig. 48—Single-Pass Weld in Steel
Z = Coarse-grained, heat-affected zone
W = Weld metal

If peening is to be effective, the coarse grains in the heat-affected zone also should be refined by hot work (peening). Any attempt by the operator to hot work the heat-affected zone so as to penetrate throughout will reduce the thickness at the heat-affected zone, which might be counteracted by upsetting the plate along the scarves before welding. Upsetting is expensive. Peening, therefore, must be confined to the weld, if it is employed at all.

Fortunately, there is a simpler and more effective means of refining the grain size and raising the ductility of steel welds than peening. Instead of making the weld in a single pass, several smaller beads are used to fill the weld groove, Fig. 49. The first bead and heat-affected zone is heated not far above the transition (critical) range by the second bead. In this way the grain size in and near the first bead is refined. The grain size of the second bead is refined by the third bead, and so on. The final bead is a reinforcing bead, so that throughout its thickness the grain size of the weld and heat-affected zone is small. Single-layer submerged-arc welds are made in steels and under conditions such that their coarse grain size is offset by other factors.

Peening may be used for other purposes than to refine the grain size. Peening spreads the weld and, if correctly

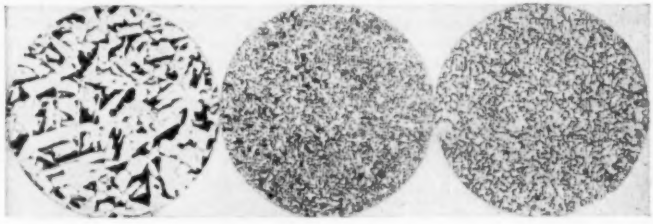
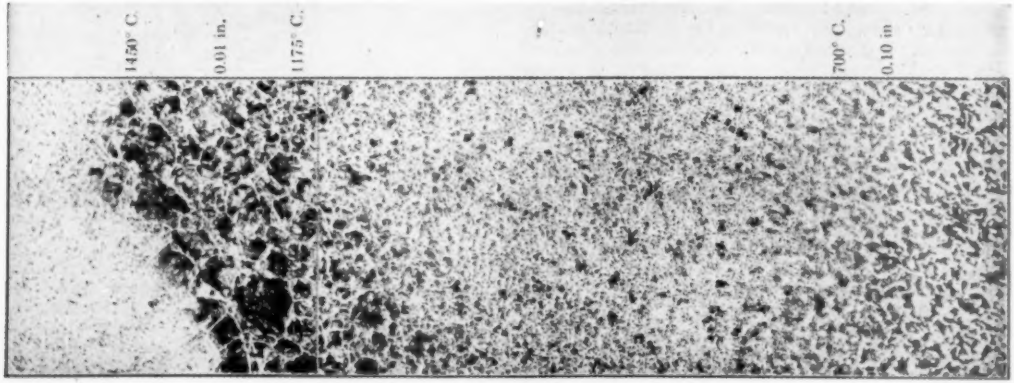


Fig. 49—Photomicrographs of Single-Layer and Multi-Layer Welds in Mild Steel

(Right) At the top is the structure of mild steel before welding. The middle photomicrograph is the heat-affected zone. At the bottom is weld metal after multiple pass welding, followed by stress relieving. (Hopkin)

(Left) At the top is weld metal deposited in a single layer by a covered electrode. At the bottom is mild steel unaffected by the heat of welding. At about 1300° F the grain size of mild steel is refined by the alpha-gamma transformation. About 2100° F grain growth has occurred. (Kinzel)



applied, will counterbalance the normal contraction due to welding. Peening thus controls distortion, that is, the change in dimensions of the part due to welding. Peening also may be used to hammer down reinforcement. Blowholes, if present, may be sealed up by peening, but it is far wiser to correct the conditions leading to the blowholes than to accept them and attempt to remove them to an uncertain extent by peening.

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(*Continued from page 138*)

undoubtedly permit more exact determination of power supply requirements and help to reduce the over-all cost for the users of this equipment.

Where the voltage drop due to the welder load is small, we have found it convenient to make simplified calculations similar to those suggested by the author, the principal difference being that we multiply the line current by the volts drop per ampere for the power system at the assumed or measured power factor for the welder load. The values of volts drop per ampere are obtained for each location using tables developed for standard equipment and unit lengths of standard conductors.

The ratio of voltage drops for an equal kva. of load drawn by the two types of welders would vary quite widely, depending on the location of the welding load, the characteristics of the power system, and the type of connections used. The advantage would of course be with the three-phase load since the current per phase is less than for an equal kva. of single-phase load.

The variation of the current at a frequency in the order of 12 cycles for the frequency-changer welder may reduce the allowable voltage fluctuation as compared with that for a conventional single-phase welder. This is indicated by our experience that a given voltage fluctuation from a seam or pulsation welder is more objectionable than the equal but less frequent voltage fluctuation caused by operation of a typical manually operated spot welder.

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(*Continued on page 186*)

PRACTICAL WELDER AND DESIGNER

Welded Design of Power Shovels and Buckets

A cost comparison between original construction methods and present arc welding shows direct factory savings up to 28% on component parts. Greater design flexibility now permits product changes at considerably less cost

by George Bain

THE component parts for the products of Bay City Shovels, Inc., Bay City, Mich., were originally manufactured from castings, forgings, rolled mill shapes and plates. Of concern to the management were production delays resulting from blowholes in castings. Component parts had to be rejected after considerable machining work was completed. Of importance also were costs necessary to build or alter patterns on short order to suit the customers' specialized needs.

Our recommended redesign to welded construction is currently being adopted on many principal shovel parts on which prohibitive costs are resulting from increases in the material expense of cast parts. Former designs now converted to welded fabrication are proving even more dependable in the field under the severest operating conditions.

George Bain is Welding Engineer, The Lincoln Electric Co., Cleveland, Ohio.

Fig. 1 Mobile power shovel

One of many different mobile power shovels designed and built by Bay City Shovels, Inc., is shown in Fig 1. Through years of uninterrupted service, these shovels have gained widespread acceptance by contractors everywhere for their superior performance and unusual stamina in handling unusually severe work in the field.

Progressively redesigned, one part at a time, many operating units of these shovels are now converted to welded construction. The resulting product improvements in greater strength and durability have been gained at substantially lower cost by weld-fabricating component parts from steel plate and standard mill shapes.

An added advantage gained is immediate processing of all rush orders since all work can now be done within

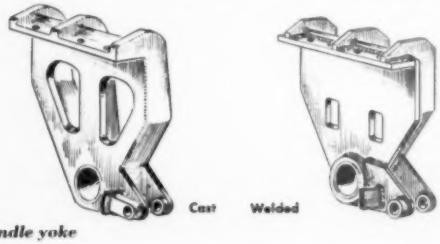


Fig. 2 Dipper handle yoke

Fig. 4 Outer boom

the plant and production schedules are not dependent upon outside sources.

Examples of component parts converted to welded design are as follows:

Dipper Handle Yoke. Material cost cut 50%. Material costs for this part became excessive in view of cast-steel prices. Machining operations also proved costly since the cast parts were difficult to hold and machining cuts often varied from $^1/_{16}$ to $^3/_8$ in. in depth. The combined material and labor costs on this part were reduced 30%. (See Fig. 2.)

Engine Support. Complicated construction necessary in the original design made material-cost-per-pound excessive. The foundry actually desired relief from this part. Parts for all-welded engine supports are now sheared from plate, formed to shape and held in a fixture for fast, downhand welded assembly. (See Fig. 3.)

Outer Boom. Formerly made by riveting—now entirely weld-fabricated from structural angles and plates. Construction has been greatly simplified with arc welding by eliminating the time and expense of fitting parts in alignment, drilling rivet holes and riveting. Field service difficulties of rivets working loose

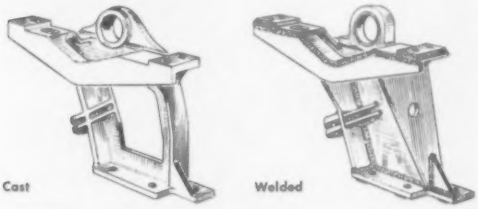


Fig. 3 Engine support

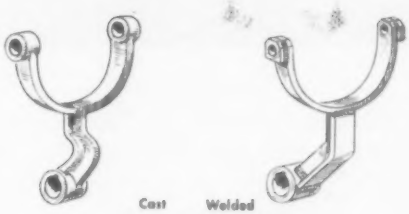


Fig. 5 Shifter yoke

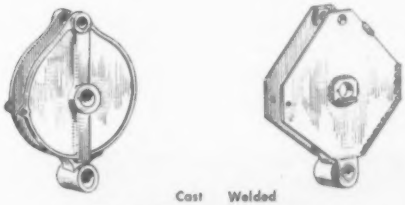


Fig. 6 Dipper sheave cage

Fig. 7 Hoist cable socket

Fig. 8 All-welded bucket

under accidental overload are also eliminated. Figure 4 shows arc welding outer sheave housing, providing solid unit construction.

Shifter Yoke. Following proved gains in sturdier welded construction at lower cost on other similar shovel parts, engineers went directly to welded construction in the initial design of this part. Valuable production time also gained on this job by eliminating the need for patterns, permitting the part to be completed in time to meet other scheduled shovel parts for an early assembly date. (See Fig. 5.)

Dipper Sheave Cage. Material costs cut 54%—manufacturing costs cut 28%. The casting for the original construction required careful straightening before loading into machining fixtures. Considerable chipping and cleaning were also necessary before machining. Dipper sheave cage is now fabricated from $^{3}/_{8}$-in. plate sheared, formed and mounted in a simple fixture for fast, easy arc-welded assembly. (See Fig. 6.)

Hoist Cable Socket. Former design required considerable straightening before it could be machined. Redesigning for arc welding permitted an additional product improvement—that of incorporating a swing-type cable guide at little addition in cost. Component

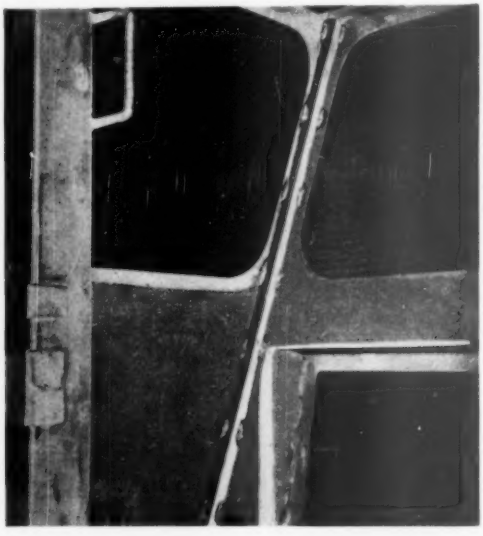


Fig. 9 All-welded cab

parts for this hoist cable socket are now flame-cut from 1/4-in. plate and positioned in a simple clamp-type welding fixture. (See Fig. 7.)

All-Welded Bucket. Originally cast steel, the shovel buckets shown are now fabricated principally from steel plate. The bottom doors were formerly of riveted construction. In the former design, considerable straightening and fitting of cast-steel component parts was necessary before riveting to correct for warpage. The doors are now entirely arc welded. Uniform quality and alignment of all mating parts are thus assured, providing maximum strength and resistance to shock. (See Fig. 8.)

All-Welded Cab. Component parts for cabs are cut from 12- and 14-gage sheet metal and mounted in a trunnion type fixture for welded assembly. The fixture swings in any position to allow fast downhand welding on all connections. Corners are reinforced with angles to form box-type construction, assuring maximum strength. These cabs are a single, solid unit of all-welded construction, proved to be more desirable to resist vibration. (See Fig. 9.)

"Deep-Fillet" Technique Is Especially Adapted to A.-C. Welding

THE "deep-fillet" welding technique, is a means of getting deeper penetration than that which can be obtained with conventional welding techniques. This deep penetration into the root of the joint makes it possible to produce smaller fillets which have the same strength as larger fillets made by conventional methods. As a result, welding speeds can often be increased considerably.

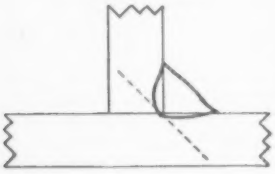
Fundamentally, this technique consists of using the proper electrode, a very close arc, a high welding current and a fast travel speed. For successful results, all of these factors must be exactly correct.

Alternating current is the natural choice for deep-fillet welding because of the high currents ordinarily employed, and because the angle of the electrode must be controlled between narrow limits. This close control is virtually impossible to maintain with direct current because of the need to manipulate the electrode to counteract the effects of arc blow, which is particularly troublesome at the high currents used for deep-fillet welding.

When a.-c. welding is used, arc blow presents no problem. Therefore, the angle of the electrode can be held easily at the correct angle up to the very limit of the speed which the operator is able to maintain.

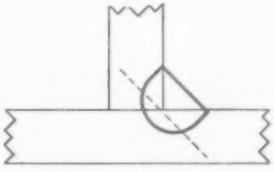
Data and sketches are through the courtesy of the General Electric Co.

CONVENTIONAL TECHNIQUE

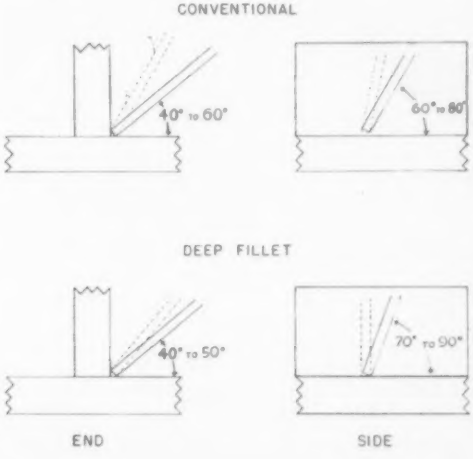


LEFT — Note that with the conventional welding technique, penetration of the weld extends slightly below the corner of the joint.

DEEP-FILLET TECHNIQUE



RIGHT — With the deep-fillet technique, penetration extends well beyond the corner of the joint. Depth of penetration is controlled by current and travel speed.



Welded Stanchions for the Barn

How one shop helped a dairy farmer cut costs

by L. M. Smith

THERE are many chances for shops in rural areas to repair and build articles for use on the farm. Here is a job that saved money and made a profit for the shop.

When a dairyman was about to rebuild his barn, the cost of ready-made stanchions seemed much too high. So he took the problem to a shop that principally does welding and cutting repair work. The shop made satisfactory barn fixtures at about half the price quoted for ready-made equipment. The dairyman saved money—the shop made a profit on the job. Here are some details that might help you to do a similar job.

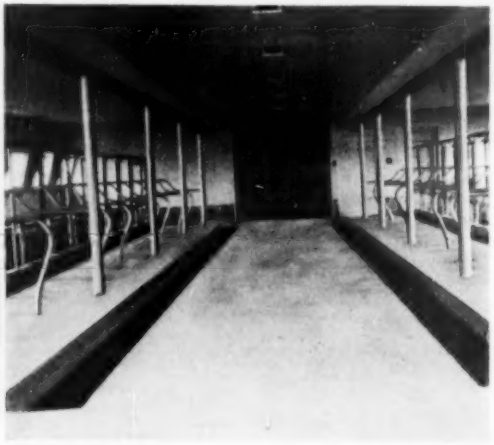


Fig. 1 Here are the stalls that were built from small diameter tubing. The curved rails were formed in the shop. All cutting and welding was done on the spot

All the fixtures were made from steel tubing less than 2 in. in diameter. All joints were oxyacetylene welded with steel welding rod. Because no flux was used it was not necessary to clean the joints before painting. All cutting and welding was done on the spot, with the exception of the curved side rails for the cattle stanchion. These were heated with the welding blowpipe and bent to the proper shape in the welding shop. To bend pipe without crimping it, fill the pipe with sand and seal the ends. Then you will get a smooth, clean bend.

Fig. 2 This shows the calf pen with special headlocks

Tubing, $1^1/_4$ in. in diameter, was used for all stalls

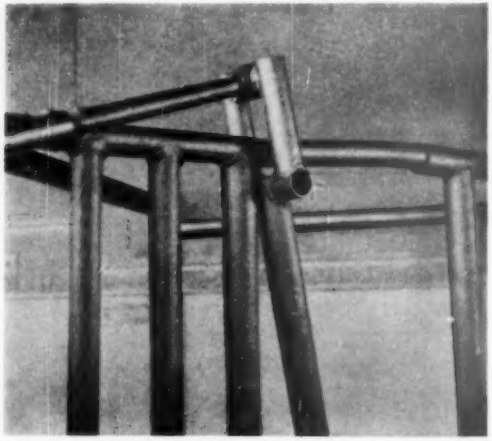


Fig. 3 Close-up of a handy headlock design. Tubing $^3/_4$ in. in diameter and steel welding rod was used

L. M. Smith is Process Service Representative, The Linde Air Products Co., Milwaukee, Wis.

and a total of 200 welds was made. In four places pipe ends had to be blanked off and in these cases orange peel plugs were made.

The bull pen required 90 welds in $1^1/_2$- and 2-in. pipe. The calf pen required 64 welds with $^3/_4$- and $1^1/_4$-in. pipe. There is an interesting design feature in the stanchions for the calf pen. Headlocks were made from $^3/_4$-in. tubing and lined up so that all or one can be opened or closed. Five of these headlock devices were made. Figure 3 shows a close-up of this arrangement.

Brazing*

THE current *Handbook* of the AMERICAN WELDING SOCIETY states:

"Brazing is usually defined as a group of metal joining processes wherein the filler metal is a nonferrous metal or alloy whose melting point is higher than 1000° F., but is lower than that of the metals or alloys being joined."

Brazing, unlike welding, does not require that the surfaces of base metals be melted; it differs from soldering, frequently termed soft soldering, in that the latter method makes use of filler metals which melt below 700° F. Some confusion has resulted from the long use of the term "hard soldering" to denote brazing in which the silver alloys which melt from about 1150 to 1600° F. are used.

Brazing depends on the limited diffusion of the filler metal into the clean surfaced, hot, solid base metal. This is in contrast with fusion welding in which intermelting of the surfaces of the base metal and the filler metal takes place to form an integral joint.

The brazing process is widely used because a great many metals can be effectively joined in that manner with a minimum of filler material and at relatively low temperatures compared with welding. Simple carbon steels† as well as cast iron, copper, nickel, Monel, Inconel, brass, bronze and other metals are commonly brazed. Dissimilar metals, even with wide variations in melting points may be joined by brazing. Great economies often result from making repairs on broken massive machine parts of cast iron, malleable iron or steel by brazing "in place"; not only is the scrapping of expensive heavy parts thus avoided, but the "down time" of the machine is minimized.

Because the temperatures of liquid filler metals run lower than in welding, local preheating‡ temperatures are correspondingly lower and less distortion is encountered. Metals, like cast iron and medium- to high-carbon steels,† which harden deeply in fusion welding with attendant danger of cracking, can be brazed readily without serious hardening of the heat affected zones.

Brazing materials commonly used fall into two broad groups: silver base and copper base alloys. The relatively low melting points of the eutectics of the silver-copper and silver-copper-zinc alloys and their excellent flow characteristics allow their use for nearly all metals. The melting points of these alloys range from about 1150 to 1600° F. The copper base brazing compositions generally contain a considerable percentage of zinc and may also include nickel, tin and phosphorus. These alloys melt from about 1600 to 2100° F., and are generally available as wire, sheet, powder or lumps, to provide the form best suited for every application. Copper and copper alloys are commonly brazed with lower melting bronze filler metal. Nickel alloys are joined by using silver brazing alloys.

The surfaces to be joined must be free of oxide to obtain a good bond. It is therefore necessary either to protect the surfaces from the oxidation which may occur during heating, or to use a flux which will remove oxide by chemical means. The flux chosen should be highly fluid at the brazing temperature, be readily floated to the surface of the brazing metal and, of course, must react with the metal oxide.

Common fluxes are chlorides, fluorides and borates. They are available as pastes and as saturated solutions. Recently fluxes in stick form have been made available. Flux may be applied to the surfaces being joined before brazing or as a powder with the brazing metal. Since entrapped slag causes lowered bond strength and fluxes are usually corrosive to the joined metals in service, flux must not be entrapped in the joint.

Heating for brazing may be done by oxyacetylene torch, in a furnace, by dip technique or by electric means. The latter may be provided by the carbon arc, electric resistance or induction methods.

Joint design and preparation are of prime importance. Surfaces to be joined besides being free of oxide must be clean and free of oil or foreign matter. It is advisable to keep clearances within a few thousandths of an inch for maximum strength, the exact distance between surfaces to be joined depending to some extent on the heating means, the type of brazing alloy selected, and the design of the part. Butt joints are undesirable because of low resultant strength; lap braze and scarfed joints should be used instead.

When metals are correctly brazed the joint will have ample strength and ductility for a great many applica-

* This article reprinted from Oct. 1949 issue *Tempil® Topics*.

† See the Tempil® "Basic Guide to Ferrous Metallurgy" which gives definitions and boundaries of critical temperatures. This 16½-x-21-in. plastic laminated wall chart in color is available free on request.

‡ See Tempil® Preheating Chart which lists recommended preheat for 79 commercial metals and alloys. Available on request without charge.

tions. It is understandable, therefore, that brazed joints are finding increasing use for new applications, as for example, the use of gold brazing of corrosion-resistant metals for corrosive conditions, and that brazing is now commonly used as a production method. It is a wise precaution, nevertheless, to test brazed joints under conditions representing severe service before going into production.

Close Tolerance of Gas-Welded Assemblies Made Possible by Unusual Rotating Jig*

ZIMMER Welding Supplies and Service of Brooklyn, N. Y. devised a unique jig for holding the three units (Fig. 1) which make up a welded air-filter part. The units are formed from 20-gage cold-rolled steel.

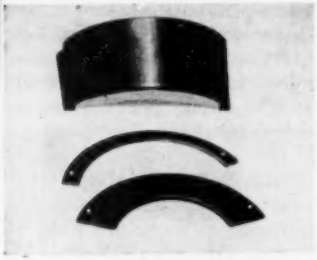


Figure 1

The jig itself is set on a platform which is mounted on a spindle to permit rotating the jig to the most convenient welding position. Two sections of pipe are welded to the base of the jig to provide the welding operator with a steadying hand rest.

The curved side sections of the jig are machined to the exact size and shape of the side filter sections. The jig side sections are grooved and the base of the jig is provided with preset stops which enable the operator to position the parts for welding in a matter of seconds. The inside grooved section and the position stops are clearly visible on the left-hand side of Fig. 2. The top curved section of the filter assembly is placed on top of the jig and is held in the proper assembled position by means of four studs which may also be seen in the illustration.

In use the side plate need not be removed from the jig, but merely loosened enough to permit the two flat side sections of the filter to be set in position. The top curved section is now placed on the jig so that it butts the side section. Finally, the jig is locked by means of a bolt set in the movable side jig section which engages threads in the jig body. This lock bolt is equipped with a Parker Kalon head which facilitates the locking and unlocking of the jig. The movable side section of the jig is always perfectly aligned as it rides on a guide stud which is set in the jig body. The guide stud and the locking bolt are visible in Fig. 2.

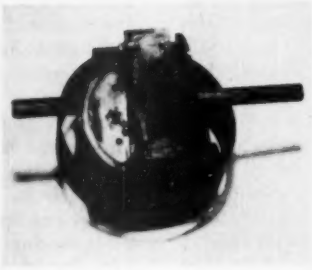


Figure 2

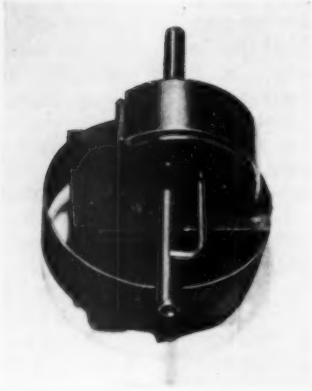


Figure 3

In Fig. 3 the filter sections have been locked in place ready for welding. The actual welding operation is shown in Fig. 4; notice how the operator is using the pipe section as a hand rest.

A.W.S. Ga 50 rod, 1/16 in. in diameter, was used with a light Welding Torch and a No. 2 tip at a pressure setting of 2 lb. for both oxygen and acetylene.

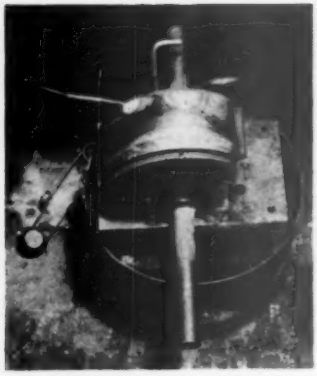


Figure 4

Figure 5

Three views of the completed air-filter part are shown in Fig. 5. A finished tolerance of 1/32 in. indicates the perfection of the jig. The saving of time in permitting any number of assemblies to be perfectly aligned and welded in a jig of this type is often the difference between a good profit or loss in fabricating jobs similar to this one.

* Data and photos courtesy Air Reduction Sales Co.

the AMERICAN WELDING SOCIETY

activities • related events

1949–50 Nominating Committee, American Welding Society

With the approval of the Board of Directors, the President has appointed the following members to constitute the 1949-50 Nominating Committee: H. C. Boardman, Chairman, Chicago Bridge & Iron Co., 1305 W. 105th St., Chicago 43, Ill.; L. C. West, Empire Structural Steel Fabricators, Inc., Syracuse, N. Y.; C. A. Lossmis, Bureau of Ships, Navy Dept., Code 692, Washington 25, D. C.; A. E. Pearson, Ingalls Iron Works Co., Birmingham, Ala.; J. F. Maine, Republic Structural Iron Works, Cleveland, Ohio; R. L. Kohlbry, Machinery & Welder Corp., 1324 W. Fulton St., Chicago 7, Ill.; Sam J. Walker, Butler Manufacturing Co, 13th & Eastern, Kansas City 3, Mo.; H. E. Rhoades, National Cylinder Gas Co., 439 Bryant St., San Francisco, Calif.

The by-laws require that these names be published in the JOURNAL on or before March 1st. The Committee is required to deliver to the Secretary in writing, on or before the 10th day of May, the names of its nominees for the various elective offices next falling vacant with the written acceptance of each nominee.

The purpose of publishing the names of the Nominating Committee in the JOURNAL is to provide every member with an opportunity to make suggestions to this Committee. To be effective, it is essential that these suggestions be sent in at once as, naturally, the Nominating Committee will be required to hold early meetings in order to fulfill its duties as required by the By-Laws.

The offices to be filled are: President, First Vice-President, Second Vice-President (all for a term of one year), Treasurer and four Directors-at-Large (all for a term of three years). Present incumbents of the offices of President, First Vice-President, Second Vice-President and Treasurer are eligible for another term. The incumbents for Directors-at-Large are not eligible for re-election, according to the By-Laws, Article VIII, Section 6. The Directors-at-Large are selected by the Nominating Committee with due consideration to geographical distribution.

Present officers whose terms expire next October are: President, O. B. J. Fraser, First Vice-President, H. W. Pierce; Second Vice-President, C. H. Jennings; Treasurer, R. S. Donald. Directors: D. Arnott, T. M. Jackson, C. I. MacGuffie and J. B. Tinnon.

Labeling of Fluoride Bearing Gas Welding and Brazing Fluxes

At the request of numerous producers and users of gas welding and brazing fluxes, the A.W.S. Committee on Safety Recommendations has been working for about a year to prepare a standard wording which could be included on the labels of fluoride bearing fluxes to inform users as to the proper safe handling of such fluxes.

At a meeting on Dec. 15, 1949, the A.W.S. Board of Directors approved adoption of the following wording:

CAUTION

Contains Fluorides

This flux when heated gives off fumes which may irritate eyes, nose and throat.

1. Avoid fumes—use only in well-ventilated spaces.
2. Avoid contact of flux with eyes or skin.
3. Do not take internally.

The adoption of this wording has been called to the attention of manufacturers of such fluxes, and it is expected that in time this standard wording will become universally used. Users are urged to carefully read the instructions to eliminate possible hazards.

Detroit Chosen for Second Conference on Electric Welding

Attendance of over 400 persons at the first "Conference on Electric Welding" in Detroit during 1948 has led sponsoring societies to choose that city as the location for a second similar conference scheduled April 5, 6 and 7. The three-day program is sponsored by the American Institute of Electrical Engineers in cooperation with the AMERICAN WELDING SOCIETY and the Industrial Electrical Engineers Society of Detroit. Technical paper sessions will be devoted to arc-welding research, arc- and resistance-welding machinery, instrumentation, stud welding, submerged arc welding, power supply problems, etc. Authors of papers plan to give practical demonstrations of the techniques and equipment covered by the articles in evening sessions which supplement the day-time program. "Conference Proceedings" pamphlets will be published, including copies of all papers and discussions.

Executive Committee Meeting

A meeting of the Executive Committee of the AMERICAN WELDING SOCIETY was held in Room 608 of the Engineering Societies Bldg., New York City, on Nov. 3, 1949, with the following in attendance:

Members: O. B. J. Fraser, H. W. Pierce, C. H. Jennings, D. Arnott, H. O. Hill and T. B. Jefferson.

By Invitation: J. B. Tinnon.

Staff Members: J. G. Magrath and F. J. Mooney.

Invitation to A.W.S. Cuban Members as Official Representatives at Havana Architects Conference.

The Secretary was directed to extend invitation to Carlos Arnoldson, Jr., and William E. Skilton, both A.W.S. members residing in Cuba, to attend the Havana Architects Conference and to act as official representatives of the AMERICAN WELDING SOCIETY at this Conference which will be held in Havana, Cuba, Dec. 8 to 14, 1949. These members are to be informed that their representation is not to be at A.W.S. expense.

"Member-Get-Member" National Headquarters Campaign.

Due to the urgency of increased membership, the Executive Committee approved of a plan whereby each member of the A.W.S. be requested to bring one new member into the fold of the SOCIETY. The campaign plan will be handled by National Headquarters and will consist of mailing to each member a letter, to go out over the signature of O. B. J. Fraser, President, stressing the importance of greater A.W.S. membership, together with a membership application form.

A.W.S.-N.E.M.A. New York City Building Code Committee Activity.

President Fraser advised that an informal committee is now operating with scope covering activation of methods of securing revision of the present New York City Building Code in connection with welding and now consisting of members of the AMERICAN WELDING SOCIETY and the Welding Section of the National Electric Manufacturers' Association.

The informal committee now consists of Ira B. Yates, *Chairman*, J. G. Magrath, E. Vom Steeg, Jr., G. N. Bull and L. D. Price, with A. N. Kugler as assistant to Mr. Yates, S. A. Greenberg as assistant to Mr. Magrath and Henry Dreher, assistant to Mr. Price.

It was voted that J. G. Magrath's participation as Secretary of this activity be approved.

Consideration of Plan for Two Candidates for Each Office on Ballot as Selected by National Nominating Committee.

Chairman Fraser explained that there were two issues at hand, namely (1) the ethical points of campaigning, and (2) the mechanics of election. After considerable discussion, the Executive Committee voted to refer the ethical points of campaigning to the Code of Principles of Conduct Committee and for Mr. Fraser to appoint a special committee of three to study the mechanics of election and for this committee to submit its recommendations to the Board of Directors.

Joint A.W.S.-Purdue Conference.

Consideration was given to an invitation extended by C. E. Martin, of the University of Purdue at Lafayette, Ind., to the AMERICAN WELDING SOCIETY to co-sponsor the Purdue Welding Conference which will be held in the spring of 1950.

Discussion followed during which it was pointed out that many universities in various sections of the country are now or are planning to hold such conferences in the future and that it would be unwise for the AMERICAN WELDING SOCIETY to establish a pattern at one point in that the SOCIETY would be requested to similarly collaborate with other universities. Such an activity could not be sustained. Final recommendation was that A.W.S. should not sponsor a joint conference with Purdue or any other university. Instead, it would be recommended to local A.W.S. Sections that they cooperate with such activities when held by nearby universities.

Recommendation of Activity in Connection with Approved A.W.S. "Welding Engineer" and "Welding Engineering" Definitions.

The Secretary recommended that the Educational Committee be requested to (*a*) prepare a recommending study course for universities and other educational groups interested in incorporating welding engineering to a greater degree in their curriculum, and (*b*) to prepare a suggested pattern for examination of applicants seeking state licenses for practicing Welding Engineering.

A.W.S. National Headquarters' Housing.

After discussing the matter, Mr. Fraser was authorized to appoint a special committee to consist of three members, to study A.W.S. National Headquarters' housing problem. This committee should consist of people with a business background.

Appointment of New Members to Serve on "Special Committee on Handling Requests for Foreign Libraries"

A ruling by the Executive Committee in March 1943 stated that this Committee be composed of the Treasurer, the Publication Committee Chairman and the Editor.

Upon motion, duly seconded, the attending Executive Committee members, with the approval of the President, voted to relieve Messrs. Weigel and Arnott from this Committee, and appoint in their place R. S. Donald, Treasurer, and A. G. Oehler, Chairman of the Publication Committee, in order to comply with ruling made by the Executive Committee in March 1943.

Monetary Returns from Space Sale at 1949 National Metal Exposition.

The Secretary reported that $7017.54 income was received from the American Society for Metals for welding space sales at the 1949 National Metal Exposition.

The Executive Committee directed the Secretary to send W. H. Eisenman, Director of the National Metal Exposition, a letter of appreciation and thanks for the splendid work he did in conducting the Exposition at the 1949 Annual Meeting

Securing of Convention Headquarters Two Years in Advance

The Secretary observed that it is necessary that activity for securing Convention Headquarters be started two years in advance and also requested the Board to approve of the selection of the Hotel Sherman in Chicago as A.W.S. Headquarters for our 1950 Annual Meeting.

The Executive Committee approved of the selection of the Hotel Sherman as Headquarters for A.W.S. 1950 Annual Meeting and for the Convention Committee to instruct the Secretary to make arrangements for Convention Headquarters for the 1951 Annual Meeting, which is scheduled to be held in Detroit, Mich.

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Joint Committee on Effect of Temperature on Metals Has Active Program

Technical Symposiums and Papers Being Developed: Research Projects Under Way in Joint A.S.T.M.-A.S.M.E. Committee.

In order more effectively to carry out its various activities the Joint Committee on Effect of Temperature on the Properties of Metals, which functions under the auspices of the American Society for Testing Materials and The American Society of Mechanical Engineers, has virtually completed reorganization of its subcommittees and personnel. This group, always very active in sponsoring technical papers and symposiums, has several papers and reports under way including two symposiums—one covering "The Effect of Sigma Phase on the Properties of Metals at Elevated Temperatures," the other dealing with "The Corrosion of Gas Turbine Materials." These symposiums will each include eight to ten papers, and are scheduled for presentation at the A.S.T.M. Annual Meeting in Atlantic City the week of June 26, 1950.

Personnel

The Committee is headed by Ernest L. Robinson, Structural Engineer, Turbine Engineering Divisions, General Electric Co., Schenectady, N. Y., with Howard C. Cross, Battelle Memorial Institute, Columbus, Ohio, Secretary; Francis B. Foley is the Vice-Chairman; and serving with these three officers as the Executive Committee are Past-Chairman Norman L. Mochel, Manager, Metallurgical Engineering, Westinghouse Electric Corp., Philadelphia, Pa., and A. J. Herzig, Chief Metallurgist, Climax Molybdenum Co., Detroit, Mich. The Panels and Subcommittees of this joint group are as follows (each Panel includes from 6 to 25 men who are leaders in the specific fields covered in the panel work):

Finance, N. L. Mochel, *Chairman.*

Aviation, Leo Schapiro, Douglas Aircraft Co., Santa Monica, Calif., *Chairman.*

Data and Publications, R. F. Miller, Carnegie-Illinois Steel Corp., Pittsburgh, Pa., *Chairman.*

Gas Turbine, C. T. Evans, Jr., Elliott Co., Jeannette, Pa., *Chairman.*

General Research, A. J. Herzig, *Chairman.*

Papers and Meetings, H. C. Cross, *Chairman.*

Petroleum and Chemical, C. L. Clark, Timken Roller Bearing Co., Steel & Tube Div., Canton, Ohio, *Chairman.*

Steam Power, N. L. Mochel, *Chairman.*

Project 18, "Effect of Manufacturing Variables on the Creep Properties of Steel," H. C. Cross, *Chairman.*

Project 29, "Stability of Steels as Affected by Temperature," J. J. Kanter, Crane Co., Chicago, Ill., *Chairman.*

Activities

The scope of this Committee is as follows: "To sponsor investigations leading to the accumulation, evaluation and dissemination of data on the engineering properties of metals at high and low tempera-

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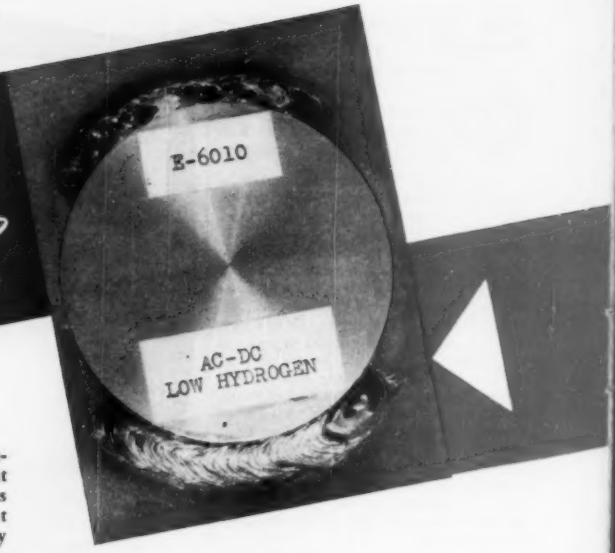

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3. Welds can be successfully enameled without heat treatment—as has been actively demonstrated on both a laboratory and production basis.

4. Materially improved operating characteristics—G-E low-hydrogen electrodes are extremely flexible in application, with either a-c or reverse polarity d-c; spatter is minimized, deposition efficiency is high, penetration is adequate but not excessive. There is little or no tendency for surface holes to occur in metals of relatively high sulphur content—and in all cases the finished weld offers an excellent appearance. (Note lower bead in photo above.)

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W-60—For welding hardenable steels where hazards of underbead cracking are to be eliminated.

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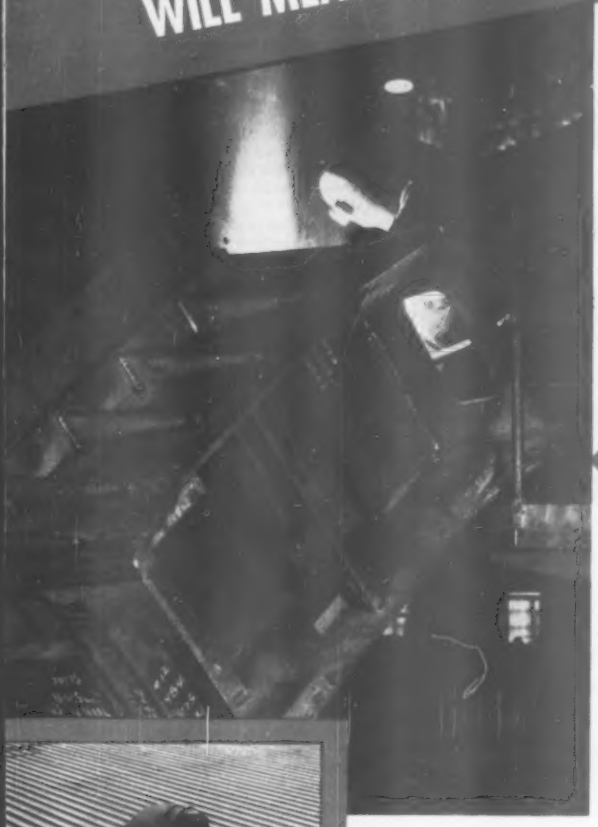
W-62—For use on steel castings and for producing weld deposits having high impact properties at subzero temperatures.

AND THESE OTHER G-E ELECTRODES CAN DO AS MUCH FOR OTHER WELDING JOBS

Mild-Steel and General-Purpose Electrodes—This group of 9 types is headed by W-28, a new general-purpose, all-position rod with an unusually stable arc that produces welds of superior appearance, at high speeds, with minimum convexity. Other electrodes in this group are available specifically for horizontal, vertical, or over-head welding, etc. **Stainless Steel Electrodes**—27 types (16 for d-c, and 11 for a-c or d-c) make this one of the most complete stainless lines available. Each type is keyed to specific AISI code numbers for easy selection. Special, double-carton packaging protects the rod against moisture as well as providing extra protection against transit and storage damage.

Cast-Iron, Hard-Surfacing, & Phosphor-Bronze Electrodes—Herein are some of the more recent additions to the G-E electrode line; W-2075 for making machinable welds on cast-iron; W-94 for abrasion-resistant, hard-surfacing applications; and W-70 for phosphor-bronze welding. They are exemplary of G. E.'s welding laboratories' constant search for better electrodes, improved equipment, and more efficient welding processes.

HERE'S WHY G-E LOW-HYDROGEN ELECTRODES WILL MEAN MONEY IN YOUR POCKET



HERE'S WHAT USERS FIND WITH G-E "LOW-HY" ELECTRODES

Production had virtually stopped at a Pennsylvania machinery manufacturer's plant because cracks were developing in weld-fabricated steel parts. A rush shipment of W-32 from our Philadelphia distributor eliminated the cracking and had them back in production the same afternoon.

Arc welding in general and W-32 electrode in particular played an important part in fabricating this ram or slide for a 200-ton, straight-side crank press. Welded construction with W-32 was used extensively throughout the entire press.

A mid-western transformer manufacturer now swears by W-32 after finding that it completely eliminated a severe cracking and porosity problem in the fabrication of transformer tanks.

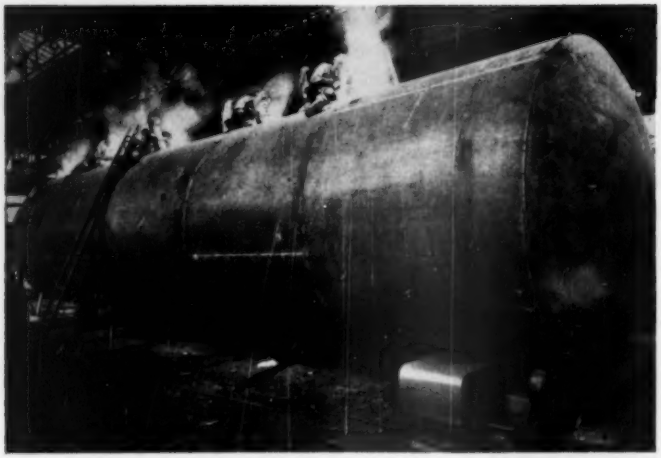
You can order these low-hydrogen electrodes from your G-E Arc-welding Distributor today. And ask him for your copy of the new pocket-sized electrode catalog, GEC-482. ***Apparatus Department, General Electric Company, Schenectady 5, N. Y.***

Copyright 1949, General Electric Company

"A-C or D-C . . . there's G-E Arc-welding Equipment for Every Application!"

ARC WELDERS • ELECTRODES • ACCESSORIES

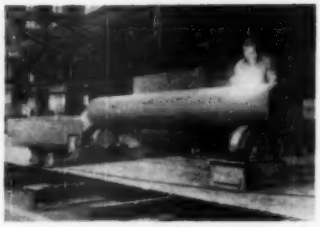
GENERAL ELECTRIC



Less Handling—More Welding

It's handling that costs most in welding . . . the crane work or manual labor in positioning the pieces—plus the welder's *waiting* time.

Get more arc-time from every hour by using Worthington-Ransome Turning Rolls to handle tanks, drums or any type of cylindrical vessel regardless of size. They continually bring the work into position for efficient, economical *downhand* welding (manual or automatic) with heavier electrodes which means fewer passes and better welds.



50% greater production on both repetitive and job work has been reported by users.

Capacities from 3 to 75 tons, up to 14 ft. diam., stationary or self-propelled. (Rolls for heavier or larger work also available.)

WORTHINGTON

WORTHINGTON PUMP AND MACHINERY CORPORATION

Welding and Assembly Positioning Equipment Division

DUNELLEN, NEW JERSEY

Y9.7

Worthington Pump and Machinery Corp.
Dunellen, N. J.

Please send Bulletin 228 on Worthington-Ransome Turning Rolls.

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tures and the standardization of test methods pertaining thereto."

While a great portion of the committee work has involved research, two existing standards are included in its responsibilities covering Recommended Practices for Short-Time Elevated-Temperature Tension Tests and Long-Time Creep Tests. Other proposed standards are being developed including one for stress rupture tests of metallic materials. Two extensive research investigations are currently under way under the Committee auspices. One on the effect of variables on the creep resistance of steels includes studies currently of major interest on the effect of varying silicon-aluminum ratios (Project 18). Certain phases of graphitization of steels are being studied in Project 28 with long-time aging tests and carbide extraction studies, particularly to ascertain the role of aluminum, under way. A progress report on this work is expected in June 1950.

The Joint Committee is sponsoring the publication by A.S.T.M. of a comprehensive series of data and curves covering the high temperature creep and rupture strengths of wrought steels, including many of the highly alloyed and austenitic varieties. Compiled by J. J. Heger and R. F. Miller, Carnegie-Illinois Steel Corp., the book should go a long way toward answering persistent demands for authoritative information on many of the steels that have come into widespread use, particularly in recent years. Development of similar data on castings is under way.

The "Effect of Structural Changes on the Properties of Ferritic and Austenitic Steels" will be the subject of two technical papers now being prepared. A bibliography covering "Heat Embrittlement" is to be brought up to date. The committee hopes to sponsor a 3-year summary of the intensive studies recently carried out on the graphitization problem. Other work, particularly of interest to the Steam Power group, involves thermal shock and distortion, and design factors such as Poisson's ratio, and the modulus of elasticity. Data and bibliography will also be compiled on "Coefficient of Thermal Expansion."

A technical paper is to be arranged covering "The Use of Austenitic Steels in the Petroleum Industry."

The Aviation Panel has some important studies including a "Statistical Evaluation and Analysis of Some Airframe Sheet Materials" and this group is also studying sheet materials for power-plant applications. The group concerned with Gas Turbine problems is completing its "Recommended Practice for Conducting Stress Rupture Tests at High Temperature" and is studying high-temperature stress rupture and fatigue of notched test bars.

This panel is investigating the corrosion of metal by various oil ashes and methods of protecting the different alloys. It is sponsoring the Symposium on Corrosion-Erosion of Gas Turbine Materials. A technical paper is being developed on statistical analysis using as a basis data from an extensive program of stress rupture tests. The group concerned with General Research is sponsoring the Symposium on the Effect of Sigma Phase. It

is considering various methods of making and reporting creep tests.

Year Book

The A.W.S. 1950 Year Book is now available to the membership upon request.

1949 Bound Volume

Copies of the 1949 Bound Volume of THE WELDING JOURNAL are now available. The price is $15. Order through the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

Bound Volumes Welding Journal

The SOCIETY will not be able to accept requests for individual binding of issues of THE WELDING JOURNAL for the year 1949. We will, however, furnish members who want their JOURNALS bound with a 1949 bound volume cover at a cost of $1.00 plus postage. The actual binding of the JOURNALS will have to be completed locally. Order through the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

New Sustaining Members

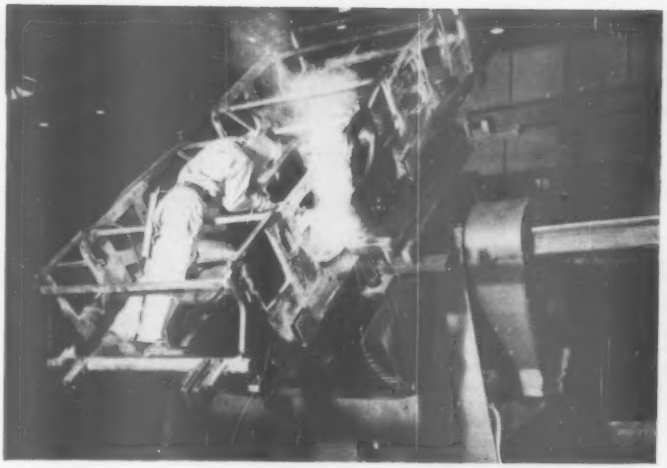
The following have recently become Sustaining Members:

L. E. Conklin, Sustaining (A) Member Representative, Foster Wheeler Corp., 165 Broadway, New York 6, N. Y.—Manufacturers of Industrial, Marine and Naval Boilers, Condensers, Economizers, Evaporators, Air Heaters, Feedwater Heaters and Superheaters; Cooling Towers, Heat Exchangers, Dowtherm Heating Equipment, Package Steam Generators, Expansion Joints, Pumps (Centrifugal and Vacuum), Pulverized Fuel Equipment, Steam Accumulators, Steam Ejectors, Waste Heat Boilers, Vacuum Refrigeration Machines, Water Cooled Furnaces, Fractionating Towers, Petroleum Processing Plants and Complete Refineries, Industrial Processing Installations and Chemical Plants; Electric Combustion Controls, Regulators, and Actuators, Karbate Equipments and Stedman Packing Units.

H. W. Pierce, Sustaining (A) Member Representative, New York Shipbuilding Corp., Camden, N. J., designers and builders of all classes and types of naval and merchant ships. Five of the ten building ways are under cover, with overhead crane equipment capable of a 300-ton lift. Complete shop facilities for the fabrication of fired and unfired pressure vessels to all code requirements, steel and alloy pressure piping and heavy industrial equipment to customers' design and specifications.

Eugene R. Ford, Sustaining (A) Member Representative, Ford Motor Co., Dearborn, Mich., manufacturers of Ford cars and trucks, Lincoln and Mercury cars, buses and Ford tractors.

R. Barlow and A. E. Lindsey are already Sustaining (A) Member Representatives.



More Arc-Time Per Hour

You pay your welders for welding . . . so the time it takes them to *position* the work—or themselves—is *lost* welding time.

But a Worthington-Ransome Positioner quickly tilts and rotates the work for practically *continuous* welding—always in the efficient *downhand* position that permits using heavier electrodes for *quicker, neater, better* welds.

Mass production or job welding . . . small pieces or "crane" work . . . automatic or manual welding—Worthington-Ransome Positioners quickly *pay* for themselves with increased production, lowered labor costs—up to 50%.

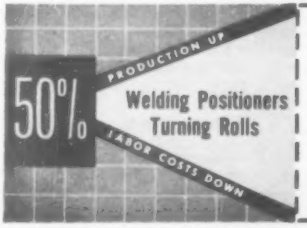
Capacities from 100 lb. to 20 tons.

WORTHINGTON

WORTHINGTON PUMP AND MACHINERY CORPORATION

Welding and Assembly Positioning Equipment Division

DUNELLEN, NEW JERSEY



YD-6

Worthington Pump and Machinery Corp.
Dunellen, N. J.

Please send Bulletin 210C on Worthington-Ransome Welding Positioners.

NAME.....

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NEW LITERATURE

New Calcium Carbide Federal Specification

The International Acetylene Association announces it has given assistance to the Federal Specifications Board in the preparation of a new Calcium Carbide Federal Specification. The new specification for Calcium Carbide, O-C-101a, is available from the Superintendent of Documents, Government Printing Office, Washington 25, D. C., at a cost of five cents per copy.

Hobart Arc Welding News

Volume VI, No. 3, "Hobart Arc Welding News," a 24-page booklet chock-full of interesting photographs and articles on welding from all over the country, is now being mailed.

This publication is mailed free of charge to anyone interested in arc welding and will be mailed immediately on request to the publisher, The Hobart Brothers Co., Troy 1, Ohio.

Ampco News

Ampco Metal, Inc., Milwaukee 15, Wis., have published another issue of the *Ampco Welding News*. Actual stories concerning the economy of Ampco welding electrodes when used in salvage, maintenance and production are included. Copies of this issue will be furnished upon request.

Metal Industry in Germany

The British Information Services, 30 Rockefeller Plaza, New York 20, N. Y., has issued two reports as follows:

BIOS Over-all Report No. 15, "The Ferrous Metal Industry in Germany During the Period 1939–1945," 270 pages, $1.15, postpaid.

BIOS Over-all Report No. 23, "The Non-Ferrous Metal Industry in Germany During the Period 1939–1945," 198 pages, 90¢, postpaid.

These reports are issued in book form with paper covers.

Cold Pressure Welding

The Koldweld Corp., 10 E. 40th St., New York 16, N. Y., has issued a four-page leaflet giving technical information on the Koldweld Process; the advantages, range of application and other similar information. The manner in which licenses may be secured is also outlined. Copy available on request.

Vacuum Hose

Industrial vacuum hose, which handles dust, abrasive scrap and toxic fumes in many industries, is pictured and described in the latest catalog section on the subject issued by The B. F. Goodrich Co. Copies may be obtained by writing the company at its Akron, Ohio, headquarters.

The publication pictures and describes the construction of the various lines and types of hose, lists recommended uses and gives specifications.

Products and Processes

"Products and Processes," a booklet published by Union Carbide and Carbon Corp., describes the principal activities of the five major Corporation groups—Alloys and Metals; Chemicals; Electrodes, Carbons and Batteries; Industrial Gases and Carbide; and Plastics. Short historical sketches trace the early years of some of the companies which are now a part of the Corporation. Color views show a few of the major outgrowths of these pioneer developments.

Copies can be obtained by addressing Union Carbide and Carbon Corp., 30 E. 42nd St., New York 17, N. Y.

Materials Engineering of Metal Products

Materials Engineering of Metal Products, by Norman E. Woldman, Consulting Metallurgical Engineer and Faculty Member, Cooper Union School of Engineering and Stevens Institute of Technology Graduate School, was written with the purpose of helping the materials engineer select the type of metal or alloy which is best able to meet a given set of service conditions. No other book gives this particular type of information, which will be welcomed by writers of materials specifications, industrial designers, metallurgical engineers and mechanical engineers.

This is one of the most useful books ever published in the metallurgical field. The text is clearly and simply written with full discussions devoted to the advantages and disadvantages of all various types of metals and alloys in specific service applications. Accompanying the text are numerous tables of data on the physical properties and performance statistics together with abundant illustrations, especially those showing various types of metal failures.

The contents include: Materials for Light-Weight Construction—Introduction, Aluminum Alloys, Magnesium Alloys, High Strength Low Alloy Steels, Stainless Steels. "Materials for Mechanical Products"—Gear Material, Spring Materials, Bearing Materials, Thread Fastener Materials. "Materials for Electrical Industry"—Magnetic Materials, Electrical Contact Materials, Thermostat Metals, Electrical Resistance Alloys; "Materials for Special and Severe Service"—Corrosion and Its Prevention, Highly Corrosion-Resistant Materials, High-Temperature Metals; "Testing of Materials"—Mechanical Testing, Non-Destructive Testing; Appendix and Index.

Reinhold Publishing Corp., 330 W. 42nd St., New York 18, N. Y. Price $10.

Clothing Catalog

Aljay Mfg. Co., Inc., of 1516 Callowhill St., Philadelphia 30, Pa., who manufacture welders' leather clothing and gloves, have their new 1950 catalog sheets available. These may be obtained by writing the company.

Multi-Layer Bulletin

The market for A. O. Smith Multi-Layer Pressure Vessels is so varied that it is almost impossible to economically or satisfactorily direct a single bulletin into each one of these markets. In order to make the bulletin presentation of Multi-Layer Vessels as effective and flexible as possible, it was decided to separate the subject matter into component parts, each able to stand on its own merits but still interrelated with each other with the same family art treatment.

The complete Multi-Layer bulletin will be composed of the following separate increments: (1) General History of A. O. Smith Pressure Vessels (4 pages); (2) Research as Applied to Pressure Vessels (4 pp); (3) Multi-Layer Manufacture and Assembly (8 pp.); (4) Multi-Layer Design and Engineering (estimated 12 pp.); (5) Multi-Layer Penstocks (estimated 8 pp.); and (6) Multi-Layer Specifications.

Bulletin No. V-52, *Multi-Layer Manufacture and Assembly*, is available from the A. O. Smith Corp., Milwaukee, Wis.,

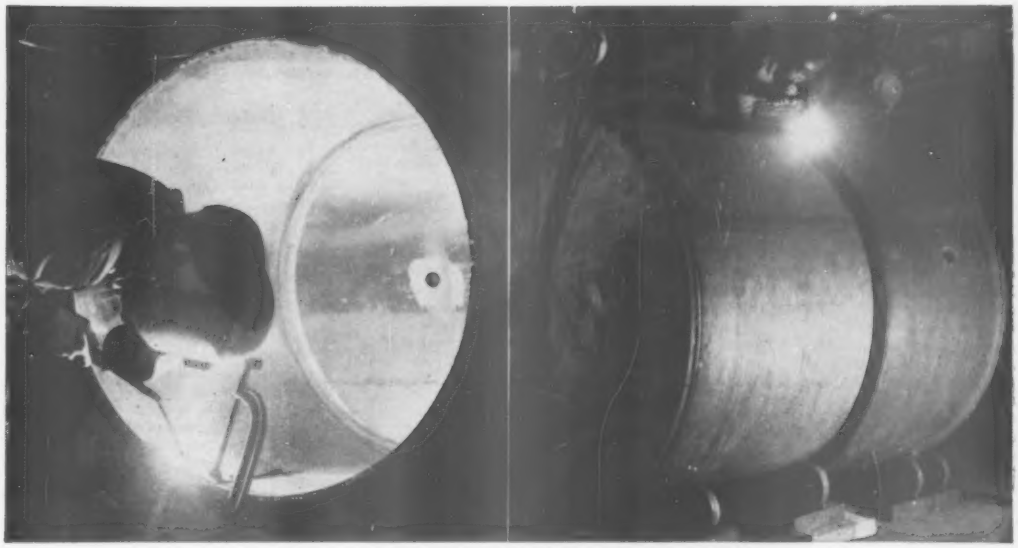
Vernier Caliper

The George Scherr Co., Inc., 200F Lafayette St., New York 12, N. Y., has issued a two-page illustrated bulletin, describing the new Mauser Vernier Caliper for outside, inside and depth measurements.

The new tool has several improvements over the well-known older models. These features are fully described in the bulletin which may be obtained by writing to George Scherr Co., Inc.

Mid-States Welder Mfg. Triples Space

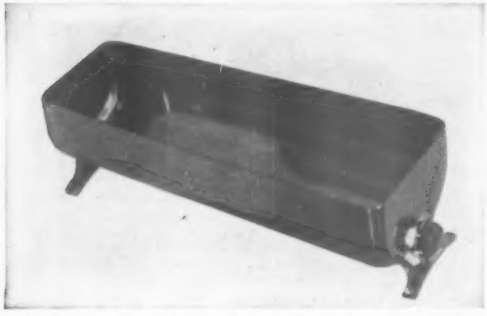
The Mid-States Welder Mfg. Co., 6029 Ashland Ave., Chicago 36, Ill., has issued a four-page brochure outlining their various types of arc welders, arch torches, saw guns and the like. Copy available on request.



Above left: Welding cylindrical tanks at S. Blickman, Inc., Weehawken, New Jersey, with new "Stainweld".
Above right: Downhand welding 18-8 stainless steel 1200 gallon still.

NEW LINCOLN ELECTRODES CUT STAINLESS WELDING COSTS

All types of stainless steel pressure vessels and containers are now being weld fabricated at lower cost with new, improved Lincoln "Stainweld" electrodes. As a result of newly developed coating, new "Stainweld" offers these cost cutting advantages:



Stainless steel trough shows high quality welds ground and polished. Courtesy S. Blickman, Inc.

- **Welds easier in flat, vertical and horizontal positions.**
- **Arc is more stable... simplifies welding in corners.**
- **Restriking is easier.**
- **Spatter is less... slag removal is better.**
- **Welds are more solid... greater freedom from pin holes.**
- **Bead surface is more uniform... needs less finishing.**

GET THE FACTS

Send for free Lincoln Weldirectory for Stainless Steel.
THE LINCOLN ELECTRIC COMPANY
Dept. 92, Cleveland 1, Ohio

Sales Offices and Field Service Shops in All Principal Cities

LINCOLN

Titanium in Steel

Titanium in Steel, by George F. Comstock, Stephen F. Urban and Morris Cohen, meets a very definite need by supplying a correlation and critical summary of available data on the use of titanium as a deoxidizer, as a carbon- and nitrogen-stabilizing element and as an alloying metal in steel.

Until recently the physical chemistry underlying the reactions of titanium with carbon, nitrogen, oxygen and other elements in steel was unknown or at best imperfectly understood. The variable solubility of titanium carbide in austenite was generally unsuspected. It is therefore of wide usefulness to have the latest information on the subject readily available in this one authoritative volume.

Brief reference to the older literature has been made so that the significant early developments are properly recorded. The emphasis, however, is on the more recent, and more accurate data, which have been summarized and correlated in detail. It should, in fact, be unnecessary for the reader to consult the original literature unless information on all the experimental details is desired.

The close association of two of the authors with highly important research in this field, and the wide reputation of Professor Cohen in the entire field of metallurgy assure the authoritativeness and thoroughness of the treatment.

Pitman Publishing Corp., 2 W. 45th St., New York 19, N. Y. Price $7.50.

SR-4 Gages

Baldwin Locomotive Works, Philadelphia 42, Pa., announces a new 12-page bulletin, No. 279-A, SR-4® Gages for Stress Analysis, which tells how to select and use SR-4 bonded resistance wire strain gages in stress analysis. It explains the fundamentals of both simple and practical strain gage circuits and instruments, illustrating eight circuits and eight different types of instruments.

Instruments range from a Wheatstone bridge control box to oscillographic equipment and automatic self-balancing indicators and recorders, and include switching units for multiple gage installations. A section on "Calculation of Gage Output" gives derivations of formulas for computing simple dynamic circuits and Wheatstone bridge circuits, and includes examples of these computations.

Strain Gage Technique

How to apply SR-4® Strain Gages, Bulletin No. 279-B, is announced by The Baldwin Locomotive Works, Philadelphia 42, Pa. This 8-page bulletin gives detailed procedures for attaching SR-4 resistance wire strain gages to surfaces and is illustrated by 18 cartoons animating the strain gages to show their reactions to correct and incorrect methods.

Instructions are given for surface preparation, cementing, clamping, heat drying, moistureproofing and testing of gages after bonding in order to assure proper application. These instructions include the variations of methods developed for four general classes of gages and to alternate methods of application.

Balance Positioning

The Aronson Machine Co., Arcade, N. Y., has issued a four-page brochure describing their various types of balance positioners. Copy available on request.

Resistance-Welding Electrodes

Welding Sales & Engineering Co., 8750 Grinnell Ave., Detroit 13, Mich., has issued a 12-page brochure describing the Tuffaloy resistance welding alloys. These cover tips and holders, bar stock, forgings, dies, seam welder wheels, tube mill wheels and castings. Corresponding R.W.-M.A. designation is given in each case. Technical information of physical properties and shapes are also included. Copy available on request.

Portable Tools

The Rotor Tool Co., 17325 Euclid Ave., Cleveland, Ohio, has issued a pamphlet on "How to Choose and Use Portable Tools," by H. P. Bailey, President of the Company. This pamphlet outlines the economic approach, fallacies in figuring, selecting the right tool and technical information. Welding is also covered. Copy available on request.

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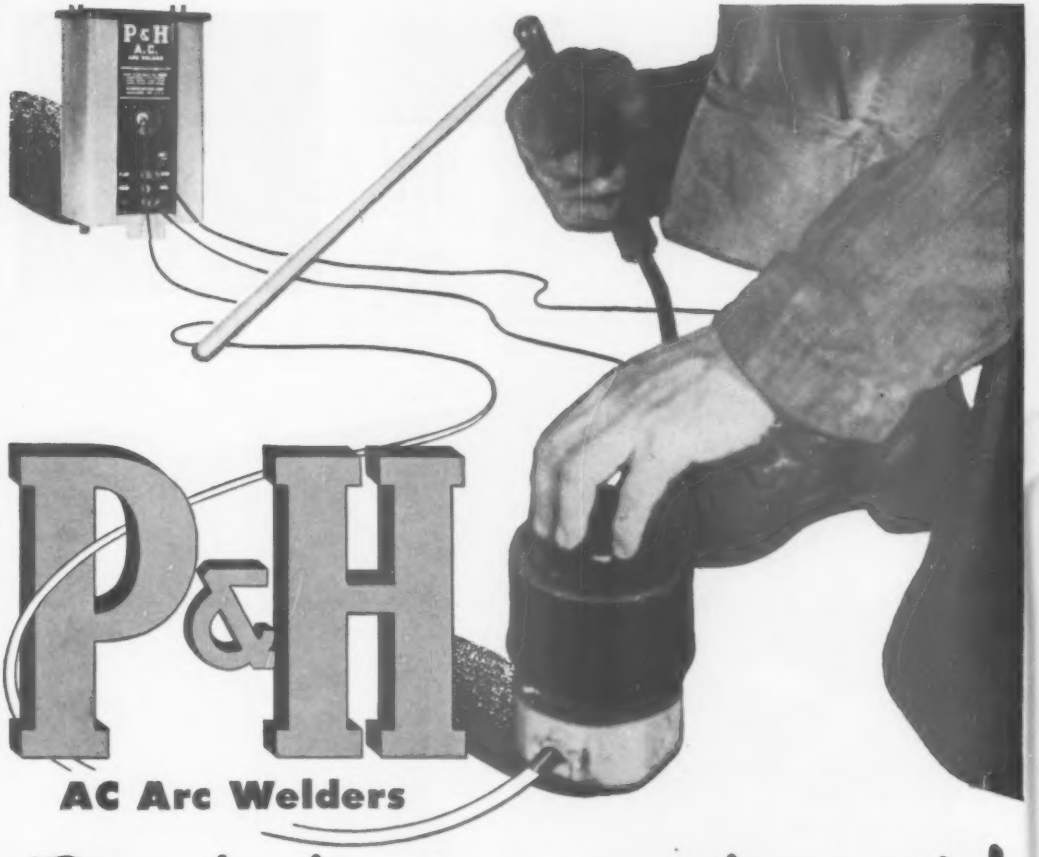


P&H

AC Arc Welders

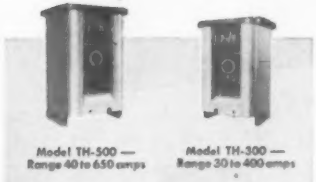
Turn the heat on – at the work!

Exclusive Dial-lectric control saves time and motion, cuts your welding costs

P&H built-in remote control puts heat selection just where your operators want it — at the work. Walking time is turned into welding time. Mount the welder on the wall—save valuable floor space. Welding is faster, sounder, better looking. Production goes up, costs go down.

Additional features are: Easy quick-start arc. Elimination of arc blow. No moving parts to cause delays or maintenance expense. High electrical efficiency that reduces power costs. NEMA rated.

See your P&H representative or distributor for full details.



Model TH-500 — Range 40 to 650 amps

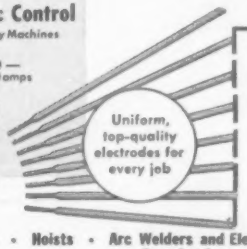
Model TH-300 — Range 30 to 400 amps

The only Complete Line of AC Welders with Dial-lectric Control

Also complete line of High-Frequency Machines

Model TI-200 — Range 30 to 275 amps

Model TI-150 — Range 20 to 190 amps



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4551 W. National Ave.
Milwaukee 14, Wisconsin
HARNISCHFEGER CORPORATION

Please send me additional information showing how P&H AC welders cut welding costs.

Name.....

Company..... Title.....

Address..... ☐ Home ☐ Business

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Excavators • Overhead Cranes • Hoists • Arc Welders and Electrodes • Soil Stabilizer • Crawler and Truck Cranes • Diesel Engines Cane Loaders • Pre-assembled Homes

PERSONNEL

Swift Joins American Brass

Clinton E. Swift, welding engineer specialist, has recently rejoined The American Brass Co., Waterbury, Conn., and will have a leading part in the company's stepped up research and promotional activities on Anaconda Welding Rods.

A 1929 University of Illinois engineering school graduate, Mr. Swift gained broad welding research experience in positions held with electrical and oil refinery equipment manufacturers, as well as during his eight years of previous service with American Brass from 1931 to 1939.

Clinton E. Swift

ANNUAL MEETING SNAPSHOTS

1. Rear Admiral Ellis Reed-Hill, U.S.C.G., Engineer-in-Chief, Chairman, Ship Structure Committee, opening Ship Structure Symposium, October 18, 1949 2. Rear Admiral Ellis Reed-Hill presents Samuel Wylie Miller Memorial Medal to A. G. Bissell, Bureau of Ships, U. S. Navy 3. Dr. C. F. Tipper, University of Cambridge, England, presents paper at Ship Structure Symposium 4. President George N. Sieger presents Certificate and Honorarium to Professor Wilbur M. Wilson, University of Illinois, 1949 Adams Lecturer 5. Captain Wendell P. Roop, USN (Retired) discusses a technical paper at one of the sessions 6. I. W. Johnson, General Electric Company, receives one of the Resistance Welder Manufacturers' Association Awards for his paper from Ben Wise, President of the Association

Photos courtesy U. S. Coast Guard

service life increased 5000%

with

AMSCO® Hardfacing!

Post Hole Digger now digs 206 holes in rocky soil before repointing

Just 4 holes was the former life of a new point and blade on this power-driven post hole digger. After hardfacing with AMSCO Tube Tungsite, the same blade and point dug 206 holes—*51 times the former service!*

Here's another example of big savings with AMSCO Hardfacing . . .

This cultivator spade gave 3 times the former service when hardfaced with AMSCO Farmface—*62 acres before, 185 after!*

These are typical examples of tremendous savings made with AMSCO Hardfacing . . . savings in time, maintenance and money! Wherever *any kind of part*—from huge mining dippers to small plowshares—is subjected to impact or abrasion, you'll find that it pays to hardface with AMSCO Welding Products.

Where to look for money-saving hardfacing applications:

On parts subject to wear by abrasion, impact, heat or corrosion, such as:

Earthmoving Equipment • Farm Equipment Oil Field Drill Bits • Sprockets • Dredge Pump Shells • Materials Handling Equipment • Pulverizer Hammers • Punching, Trimming, Forging Dies • Coal Cutter Bits.

put LIFE into service with

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WELDING PRODUCTS

AMERICAN Brake Shoe COMPANY

AMERICAN MANGANESE STEEL DIVISION

399 EAST 14th STREET • CHICAGO HEIGHTS, ILL.

NEWS OF THE INDUSTRY

Wagner Honored

J. F. Wagner, Vice-President in charge of production of the Burdett Oxygen Co., Cleveland, Ohio, was given a tremendous ovation by his fellow-employees at a banquet given in honor of his 20th year with the company on December 9th. The highlight of the evening came with the presentation of a gold watch by President William H. Loveman, who spoke of the great contributions "Joe" had made to Burdett's great growth in the past twenty years. "Gene" Morse, executive vice-president, acted as toastmaster and paid tribute to his associate by recounting many amusing and interesting incidents in their work together. Mr. Wagner is also President of the Independent Oxygen Mfrs. Assn.

He is a member of the AMERICAN WELDING SOCIETY.

National Welding Supply Assn.

The West Coast distributors of the National Welding Supply Assn. have a meeting scheduled for February 10th in California. Other meetings were held in December in Atlanta and New Orleans.

Tin Research Institute, Inc.

This corporation, with offices at 492 W. Sixth Ave., Columbus 1, Ohio, has been organized to provide free technical service to users of tin in the United States. Technical experts are available for consultation and practical assistance either at the Institute or at Consumers' plants.

R. J. Nekervis has been appointed Supervisor of Metallurgical Development and R. M. MacIntosh has been appointed Supervisor of Chemical Development. Both appointees have been with Battelle Memorial Institute for the last eight years where they have been handling problems connected with tin. All service and technical information is given free of charge and inquiries are invited.

Tube Turns Opens Canadian Branch

Tube Turns of Canada, Ltd., which was granted its Dominion charter on December 2nd, is establishing a modern plant in Chatham, Ont. The company will manufacture Tube-Turn welding fittings.

The two story plant, of brick construction, is located on the north side of Colborne St., between Adelaide and William. Preparations are now being made for the installation of special machinery and facilities, and operations will start in about three months.

Tube Turns of Canada, Ltd., is a subsidiary of Tube Turns, Inc., Louisville, Ky.

Clinic on Low Temperature Welding and Brazing

Three hundred fifty-six welders, machinists, electricians, refrigeration and maintenance men from as far as 100 mi'es away attended the Clinic on Low-Temperature Welding and Brazing at Lakeport, N. H. The purpose of the clinic was to familiarize people doing welding and brazing with the new technique of welding die-cast, brazing aluminum, copper, brass, cast-iron and all steels with low-temperature alloys. Seating arrangements were made possible by use of the school bleacher seats.

The distributor was the Ralph Smith Co., with the following as guest speaker and demonstrator: H. C. Phelps, Sales Manager of All-State Welding Alloy Co., White Plains, N. Y., with the very able assistance of Mike La Plant, salesman for Ralph H. Smith Co.

The following morning 250 high-school students attended another demonstration also at the invitation of Ralph H. Smith.

Type of Demonstration

Welders were shown how to: (1) use soot from a pure acetylene flame and then burn it off with a neutral flame to denote when the proper heat is in an aluminum casting; (2) how to weld zinc die cast by proper preparation of the break and the importance of a small flame cone; (3) how to build up worn surfaces on steel and cast iron with a hard nickel alloy that will outwear steel 10 to 16 times over under frictional wear; (4) how to braze spring steel bumper brackets and bumpers so they will hold up under shock after welding; (5) how to braze copper to copper without the use of flux; (6) how to use silver solder on dissimilar metals such as stainless steel and brass, etc.; (7) how to regalvanize a surface that has had the galvanize burned away.

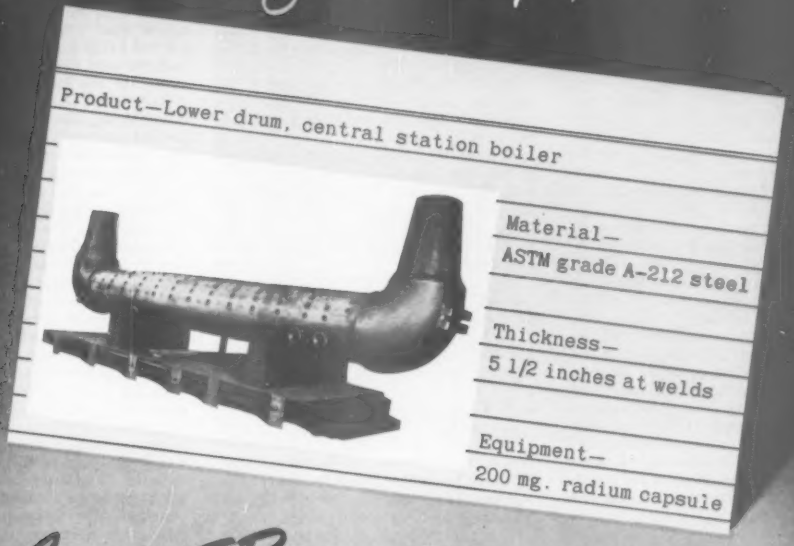
Mr. Phelps was busy until one o'clock in the morning answering individual questions after the meeting was over at eleven o'clock which shows the number of problems the average welder has to contend with daily. For instance, the garage men were interested in the welding of die-cast radiator grills, door handles and carburetor parts. The machinists were interested in a hard overlay alloy for the build-up of worn shafts, bearings, axels, drive splines, valves etc., that will machine the line of fusion, as well as anywhere and would not peel from the hardest steel and outwear the steel under frictional wear. The plumbers were interested in copper alloy to fabricate copper brass and bronze pipe that would have the corrosion resistance of the parent metal and could be used without flux on copper to copper joints. The electricians were interested in the same alloy for fabricating copper wire when they rewind the armatures of electric motors. The refrigerator repair men were interested in the same alloy for cooling systems. The garage men were also interested in a low-temperature aluminum alloy for brazing the new aluminum car fenders and an aluminum rub-on solder for a filler metal for filling the bumps in body and fenders. Sheet metal men were interested in a rub-on galvanize that meets government specification for galvanize.

Six hundred bottles of beer and 512 sandwiches were consumed at refreshment time along with a good many cases of "coke."

Lincoln Electric Distributes over $3,000,000 in Incentive Pay to Workers

The annual distribution of incentive

What's the right X-Ray film?



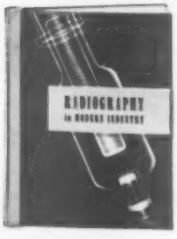
ANSWER:

KODAK INDUSTRIAL X-RAY FILM, TYPE K

● Here was thickness—thickness that demanded the fastest possible film to keep exposure time down. Gamma radiation was to be used.

So the film for the job was Kodak Industrial X-ray Film, Type K, with lead-foil screens.

This is the film that gives you the shortest exposure time for radiography by radium. You use it when checking for significant weld irregularities in thick sections.

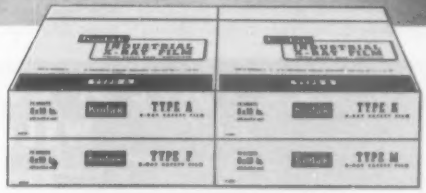


RADIOGRAPHY IN MODERN INDUSTRY

A wealth of invaluable data on radiographic principles, practice, and technics. Profusely illustrated with photographs, colorful drawings, diagrams, and charts. Get your copy from your local x-ray dealer—price $3.

Radiography

...another important function of photography



A TYPE OF FILM FOR EVERY PROBLEM

To provide the recording medium best suited to any combination of radiographic factors, Kodak produces four types of industrial x-ray film. These furnish the means to check welds efficiently and thus extend the use of welding processes.

Type K has medium contrast with high speed. For gamma ray and x-ray work where highest possible speed is needed at available kilovoltage without calcium tungstate screens.

Type M provides maximum radiographic sensitivity, high contrast, and exceptional detail under direct exposure or with lead-foil screens. It has extra fine grain and the speed is adequate for examination of light alloys at average kilovoltage and for much million-volt radiography of steel and heavy alloys.

Type A offers high contrast with about three times the speed of Type M, but with slightly more graininess. Used direct or with lead-foil screens for study of light alloys at low voltages, and of heavy steel parts at 1000 kv.

Type F provides the highest available speed and contrast when exposed with calcium tungstate intensifying screens. Has wide latitude with either x-rays or gamma rays, exposed directly or with lead-foil screens.

EASTMAN KODAK COMPANY
X-ray Division • Rochester 4, N. Y.
"Kodak" is a trade-mark

Kodak

payment checks to all workers in the Lincoln Electric Co., was made recently by James F. Lincoln, President. The 1026 checks distributed totaled $3,005,200. The average incentive check amounted to $2929, which brought the total earnings of the average worker for the year to $6078. Checks ranged from $25,000 for top managerial and engineering talent to $200 for short-time employment.

The year-end incentive payment has been distributed to Lincoln workers for 16 consecutive years.

In distributing checks Lincoln made the following statement:

"While these figures represent to Lincoln workers a great deal in security and satisfaction in their record accomplishments, the people who have benefited most by our plan of incentive management are the consumers. The selling prices of welding equipment which we manufacture are today below prewar levels.

"This record has been achieved because the objective of our incentive system and manufacturing operation is to make a better and better product to sell at a lower and lower price. All Lincoln workers are compensated in proportion to what they contribute toward the success of the company in attaining this objective. As a result all of the abilities of all of the people are directed all of the time toward this objective."

Stud Welding

Establishment of the Nelson Stud Welding Company of Canada, Ltd., with manufacturing facilities in Toronto, has been announced by Nelson Stud Welding Division of Morton Gregory Corp., and its recently appointed Canadian distributors, the Rudel Machinery Co., Ltd.

Canadian industries using the revolutionary Nelson stud-welding method for the installation of end-welded fasteners which reduce manufacturing and construction costs will realize substantial price and service advantages as a result of this step.

Most of the fasteners sold through the Rudel organization, which carries an inventory of standard Nelson MG studs and special purpose fasteners in Montreal and in its Toronto, Windsor and Vancouver branches, will henceforth be supplied from this source.

Richard C. Blankmeyer, Syracuse, Nelson Field Engineer who handled Canadian sales prior to the appointment of Rudel, is continuing as coordinator of customer service activities of the two organizations in Canada.

Fundamental Research

The Du Pont Co., announced recently that it has authorized, for the second year $100,000 for grants-in-aid to universities to "stock-pile" knowledge through the advancement of fundamental science.

These grants-in-aid are for unrestricted use in the field of fundamental chemical research. This plan of assistance was inaugurated last year by Du Pont on a trial basis with the aim of increasing the amount of such research being done in this country.

The grants are for the 1950–51 academic year. They provide $10,000 for each of 10 universities, all of which received similar awards from the company for the present school year. The company also provided $20,000 to the University of Chicago for a calender year 1950 membership in its Institute for the Study of Metals.

Recognizing that applied research in industry is dependent to a large extent upon fundamental knowledge developed by the universities, Du Pont noted that there has been a trend away from fundamental research. This was caused in part by decreasing funds available for this work from endowments. The company originated the grants-in-aid to bolster funds available for fundamental research and thus encourage American institutions of higher learning to help reverse that trend and to make further progress in the stock-piling of basic knowledge, which is a paramount need for future industrial development and for national health and defense.

In this program, the universities themselves select the research projects for which the grants will be used, the only stipulation being that they be free from any commercial implications at the time the work is initiated. Funds are intended for operating expenses such as the employment of personnel either to conduct research or to relieve the teaching load of a professor capable of carrying out research of a high order. They may also be used for the purchase of chemicals, apparatus or equipment needed in the conduct of research,

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32 pages of informative data concerning our entire line of welding rods and electrodes. Write for a copy on your company letterhead.
THE CHAMPION
RIVET COMPANY
CLEVELAND, OHIO
EAST CHICAGO, IND.

but not for new construction or endowment.

The company emphasized that there shall be complete freedom in the communication and publication of the results of the research work supported by the grants.

Institutions which will receive $10,000 grants each are: California Institute of Technology, Cornell University, Harvard University, Massachusetts Institute of Technology, The Ohio State University, Princeton University, Yale University, University of Illinois, University of Minnesota and University of Wisconsin.

New Lincoln Plant

This aerial preview of The Lincoln Electric Co's new 20-acre plant, designed and now being built by The Austin Co. in Euclid, Ohio, shows a scale model in the actual plant setting.

Lighting and ventilation will be under complete control inside the structure, which is bisected by a two-story office building entirely surrounded by the plant. A 20-ft. service corridor, extending 1427 ft. underneath the center of the plant from one end to the other, will remove all non-manufacturing traffic from the production floor.

Everyone will enter the plant and offices through a ground-level entry building adjacent to the parking area, and will pass under the railroad siding and truck docks to the service floor, where office lobby and plant entrance, personnel offices, dispensary, cafeteria and welding school will be located.

Insulated metal sidewalls, which rise 25 ft. above the brick and limestone sill wall, have steel on the interior and deep box-section aluminum panels on the outside, with Fiberglas insulation and a vapor seal between. The boiler house is located at the far side of the plant, directly adjacent to the New York Central Railroad, where an enclosed railroad siding for incoming materials extends from end to end. All production is handled in the 60-ft. aisles extending across the building from the left to the right, where the shipping aisle is served by two sidings, which are bisected by the large truck loading dock in the center.

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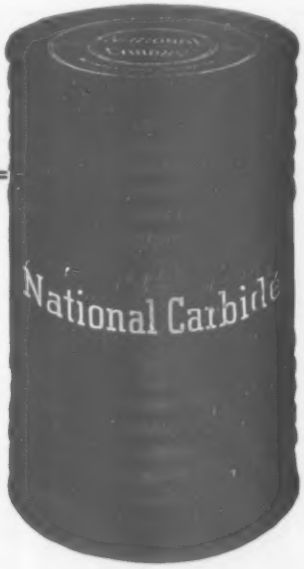

FOR WELDING and CUTTING

Use National Carbide in the Red Drum

Write us for information as to nearest available stock.

60 E. 42nd St. NATIONAL CARBIDE COMPANY New York 17, N. Y.

A Division of Air Reduction Co., Inc.

Patent Classifications

The department of welding engineering at Ohio State University has announced completion of a new Patent Classification Index in the A. F. Davis Welding Library, designed to make information on more than 12,000 U. S. patents on welding more easily available to industry and educational institutions.

Each patent in the library is classified or indexed in several different ways—by process, material, product, use, inventors name, date of issue, etc., on a single keysort card. These cards are sorted mechanically, and in very little time the numbers of patents pertaining to a given field may be determined.

The patents are divided into the 19 groups: (1) Arc Welding and Testing Procedure; (2) Arc Welding Equipment; (3) Arc Welding Electrodes, Welding Rods; (4) Electrode Holders, Welding Shields, Accessories; (5) Oxyfuel Gas Welding, Cutting, Heating and Deseaming; (6) Forge, Furnace and Thermit Welding; Soldering; (7) Butt, Flash and Stud Welding, Induction (8) Spot, Seam and Projection Welding; (9) Aircraft; (10) Containers, Pressure Vessels, Chemical Plant; (11) Electrical Industry; (12) Farming Industry, Earth-Moving, Mining; (13) Links, Chains, Rings, Bands, Hoops, Wheels, Wire; (14) Motor Vehicles, Automotive Industry; (15) Pipes and Tubes; (16) Railroad; (17) Structural Welding, Furniture; (18) Watercraft and Water Power; (19) Miscellaneous Industrial Applications.

The index covers not only the fundamental patents on welding processes and equipment but also the very important field of industrial applications of the welding processes.

Essentially, the type of information made available through the system is in the form of patent numbers relating to a designated area. Interested industrial organizations then may order those patent specifications from the patent office and refer to the material covered. The patent specifications are on file in the Davis Library and may be consulted by anyone making a search in person.

The great advantage of the Patent Index is the speed with which relevant patent numbers may be obtained. Most of the searches can be accomplished in from 3 to 20 minutes, and their value is limited only by the completeness of the patent file. It is expected that work will proceed for a number of years to expand and complete the listing of all patents relating to the welding field, according to Prof. Robert S. Green, acting chairman of the University's welding engineering department.

The use of the patent classification system is offered to industrial organizations, individuals and educational institutions. Services are free of charge to those who make use of the index system in person, but modest charges to defray clerical expense will be made for inquiries handled by mail, Professor Green announced.

New Research Laboratory of American Optical Co.

American Optical Co.'s new research laboratory in Stamford, Conn., was opened on Nov. 30 by the company's Board of Trustees which transferred its regular monthly meeting from the firm's Southbridge, Mass., headquarters to the laboratory "as a symbol of industry's interest in scientific research."

At the same time, the new research facilities were inspected by the company's Executive Committee and by a group of industrialists from the Stamford area. Joining them were U. S. Senator Brian McMahon of Connecticut, chairman of the Joint Congressional Committee on Atomic Energy; General Leslie R. Groves, wartime head of the Manhattan Project; Rep. John Davis Lodge, congressman from the Stamford district and Mayor George Barrett of Stamford.

"The research which will be conducted in the Stamford Research Laboratory of American Optical Co.," Walter A. Stewart, president, told the group at a luncheon in the Woodway Country Club, "is an extension of our long-time research program.

"We considered many suggestions of ceremony which would have been appropriate to the opening of the Stamford Research Laboratory," Mr. Stewart disclosed, "but we discarded them in order to add to the public's understanding of business' participation in scientific research. It seemed to us fitting that the laboratory should be opened by the Board of Trustees who, representing the shareholders, are responsible for the decisions which make dollars available for research program and facilities. Likewise, we felt that a regular monthly meeting of the board in the new quarters would serve as a symbol of industry's interest in scientific research."

The inspection tour of the laboratory was conducted by Dr. R. Bowling Barnes, vice-president in charge of research, assisted by A. H. Bennett, director of the Stamford Research Laboratory. Dr. Barnes explained that the laboratory supplements the research facilities and program of the company. He said that the new laboratory's program "looks to the development of new or improved scientific instruments involving optical principles and of new or improved lenses of all types including those for eye glasses." Studies will be conducted in geometrical optics, microscopy, photographic optics, spectroscopy, glass chemistry, instruments and optical materials.

Airco Simplified Structure

Simplification of the corporate structure of Air Reduction Co., Inc., in a move to consolidate activities and increase efficiency of operations, was approved recently by the Board of Directors.

This change of corporate structure, which becomes effective on Jan. 1, 1950, involves the liquidation of all the wholly owned domestic subsidiaries of Air Reduction. The respective businesses now conducted by the active domestic subsidiaries will, after Jan. 1, 1950, be conducted by corresponding divisions of the corporation. Foreign subsidiary companies are not involved.

John A. Hill, president of the company, said that the action had been decided upon after careful study and consideration of the corporate structure. "We are confident that this change not only will result in substantial economies, but will also increase the efficiency of our diversified operations," Mr. Hill stated.

The divisions replacing the domestic subsidiaries will operate in the same manner and with the same organizations as the companies they supersede, according to Mr. Hill. No changes in personnel are involved and each division head will report directly to the president of Air Reduction.

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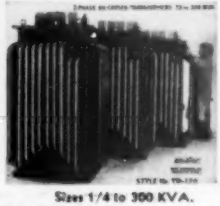
OF ALL TYPES
SIZES 1/4 TO 300 KVA.
FOR MANUAL, AIR, MOTOR, OR ELECTRONIC OPERATION,
also BUTT, ARC, and GUN WELDERS



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For Furnaces, Lighting, Distribution, Power, Auto Phase Changing Welding, and Special Jobs
AIR, OIL and WATER COOLED.
Sizes 1/4 to 300 KVA.

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No. 1 Cast Iron Welding Flux
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No. 5 & 8 Cast & Sheet Aluminum Fluxes
No. 9 Stainless Steel Welding Flux
No. 11 Tinning Compound
No. 16 Silver Solder Paste Flux

Mfg. By
ANTI-BORAX COMPOUND CO., INC.
Fort Wayne, Ind.

The ten new divisions of Air Reduction and their activities are as follows: welding equipment and compressed gases—Air Reduction Sales Co., Air Reduction Pacific Co., and Air Reduction Magnolia Co.; medical—Ohio Chemical & Surgical Equipment Co., Ohio Chemical Pacific Co. and Hospital Supply & Watters Laboratories; calcium carbide—National Carbide Co.; dry ice—Pure Carbonic Co.; export-import—Airco Company International; and the Airco Equipment Manufacturing Division.

Off to Lagos

The "Equity" 45-ft. welded tug and 30-ft. welded water taxi shown below are about to be loaded on board ship for Lagos, Nigeria, West Africa.

These sturdy little all-steel tugs, workboats and other Equity standard items of floating equipment are finding their way into all parts of the world.

They will be found in Douala, West Africa, French Indo China, Columbia, Ecuador, Venezuela, Rio de Janeiro, Belem, Brazil, Caracas, Maracaibo, Puerto Rico, Trinidad, Porto Barrios as well as in Central America, Mexico and the United States.

The Equity water taxis are furnished either with gasoline or Diesel engines, they are model tested and major operators everywhere acclaim their performance and construction.

The 45-ft. Tug is a stock item and carries an A.B.S. certificate.

Other Equitable Standards, include larger tugs, quarterboats, shallow draft tow boats, barges, dredges, etc.

Equitable Equipment Co., Inc., of New Orleans, invites your inquiries.

First Aluminum Gas Line Now Being Built

The first aluminum gas line to be installed in the nation will be an all-welded line that will extend underground approximately 1.8 miles from the main trunk line of the Alabama-Tennessee Natural Gas Co. to the Listerhill, Ala., plant of Reynolds Metals Co. The line is being installed by Lehman Hoge & Scott of Sheffield, Ala., and will be owned by the Alabama-Tennessee Natural Gas Co. Work started December 12th.

It is expected that work on the line will be completed by the first of the new year. The line consists of extruded (not drawn) type 63S-T6 aluminum alloy pipe, measuring $8^5/_8$ in. outside diameter. Walls will be $^1/_4$ in. thick. The line is designed for a working pressure of 200 per square inch, and a bursting pressure of 1750 per square inch.

Pipe will arrive on the site in 40-ft. lengths and be joined by straight butt welds. Ends will be prepared for welding by making a 30° bevel at the mill so no end preparation will be necessary on the site. The weld will be made with two passes, using $^3/_{32}$-in. diameter 5% silicon-type aluminum rod. No flux will be employed since the Heliarc method will be used. This system provides a complete shield of inert gas around the weld zone, protecting the weld and surrounding metal from the action of the atmosphere.

A 300-amp. portable gasoline-engine-driven Hobart Heliarc welder will be used, and operated at full output.

After welding, the entire length of the line including joints will be wrapped by applying cold No-Oxid pipe wrap, made by Dearborn Chemical Co.—except a single 40-ft. section which will be left unwrapped to determine if wrapping is necessary. This section will be by-passed with another length of pipe which will be wrapped. Valves will disconnect the unwrapped section from the line and allow the gas to flow through the by-pass.

It is planned to dig up the unwrapped section of the line at six-month intervals for examination. Some experimental work already completed has indicated that the wrapping of the aluminum pipe may not be necessary.

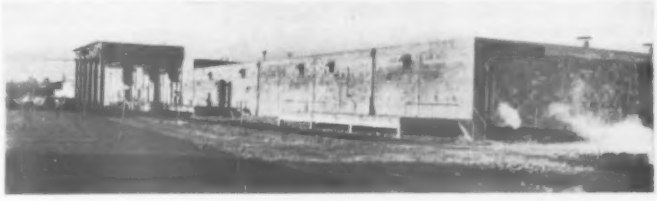
A careful cost analysis is to be made of this installation to furnish factual information for comparison with other types of lines. It is expected that important economies in installation and maintenance may offset any differential in material cost.

New Larkin Plant

On Nov. 1, 1949, Larkin Lectro Products Corp. moved their entire manufacturing facilities to a 75,000-sq. ft. building in Pine Bluff, Ark.

Production has already resumed and Larkin transformers, resistance welding equipment and are welders are being manufactured in their new location.

This was an expansion move intended to enlarge their production facilities in power and distribution transformers up to 10,000 kva., 69,000 v.



New Larkin Plant

WELDING CONNECTORS
Saxe System Welded Connection Units
for welded assembly

Saxe Units place in position and securely hold together structural parts to be welded.

As used in many welded structures they *eliminate all hole punching* producing an economical, rigid, safe and quickly erected structural frame.

"Write for 58 pg. Manual containing full engineering design information for welded structures."

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NEW PRODUCTS

Improved W-22 (A.W.S. Class E 6010) Arc-Welding Electrode

A new improved arc-welding electrode, the W-22 (A.W.S. Class E 6010) a reverse polarity d.-c. rod, has been announced by General Electric's Apparatus Dept.

The new W-22 electrode is designed specifically for vertical and overhead welding of all types of joints in mild steel. Because of its penetrating arc the W-22 is suited for welding galvanized plate stock. This penetration also facilitates the welding of lap joints and edge welds.

High tensile strength and ductility with good impact resistance are featured properties of the W-22 electrode welding bead. The new electrode may be used for the repair welding of castings because of its low volume slag-forming characteristics.

The stable arc produces weld deposits of very smooth contour in horizontal and overhead positions without the necessity of oscillation.

Brazing Costs Reduced

A 30 to 52% reduction in the cost of silver brazing preforms is offered users because of a new method of coining silver-alloy washers for various fusing, bonding, brazing and soldering operations. Developed by the Lucas-Milhaupt Engineering Co., 5057 South Lake Dr., Cudahy, Wis., the process forms a washer by subjecting round wire rings to 180,000-lb. pressure per square inch between polished dies. These sizable savings are possible because the novel method completely eliminates costly dies and excessive scrap associated with conventional stamping methods. Only as much of the silver alloy is used as is necessary to form the washer.

Available in Easy-Flo and Sil-Fos, washers can be produced in a variety of shapes and sizes, according to individual specifications. Economically coined washers are especially suitable for silver brazing, soldering or joining of metals requiring costly silver alloys. First cost savings, along with improved, faster handling and elimination of waste lower finished product cost and are reflected in greater profits and increased buyer good will.

Because flat rings fuse into metals more readily, forming a more perfect bond and seal, they are replacing wire rings formerly used in joining fittings for drain plugs on crank case pans, differential housings and fluid drive seals. They are also widely adaptable for bonding and joining applications in the refrigeration, heating and air conditioning, food processing and other equipment manufacturing industries where extra strong joints or air-tight seals are essential. Other features include convenient packaging for easier handling and safe storage, and protection against damage and loss.

Cast-Iron Electrode

Bent Laune, President of All-State Welding Alloys Co., Inc., 273 Ferris Ave., White Plains, N. Y., recently announced a new and superior cast-iron electrode that is completely competitive in price.

This new electrode has a core that is more than 99% nickel and it is 15 in. long instead of the usual 14. The electrode is designed for a. c. or d. c. straight or reverse polarity and amperages ranging from 40 to 180 depending on diameter. It is recommended for general welding of cast iron and especially wherever free machinability and color match are required.

Welds made with this electrode are ductile and 100% machinable even at the bond. Tensile strength is 30,000 to 50,000 psi. Specific advantages claimed for it also include: smooth deposit—a finish job practically free of spatter; flux residue more easily removed; welds cold; avoids cracking, distortion; no fumes; All-purpose; all types of joints; and all positions.

This new electrode is designated as All-State No. 8 New Machinable Cast-Iron Electrode. It is being made available through All-State distributors. A typical price is $1.30 for the $^3/_{16}$ in. diameter in 200-lb. lots.

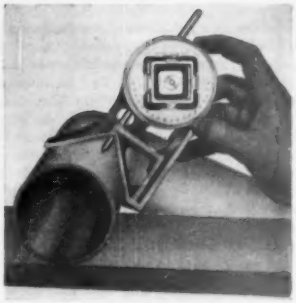
Pipe Fitters Special

To fill the need of a Center-Finder for use in "tight spots," the Model PF "Pipe Fitters Special" is now available. This compact tool has all the main features of the larger tool (Model C-1), but is handier. It is designed to speed up layout work on the job.

In laying out templates on large pipes for angle cuts, it is necessary to divide the circumference into 4 to 8 equal parts. This is usually done empirically with a steel tape. This method is not precise, as the steel tape often slips, giving inaccurate ordinate points. With the Center-Finder accuracy is assured. Features of the Pipe Fitters Special Center-Finder include:

The revolving dial with the 4 levels marked in both degrees and inches per foot.

The tool is very light; weights only 6 oz. Pocket size, it measures 6 x 4 x $1^1/_4$ in. overall.

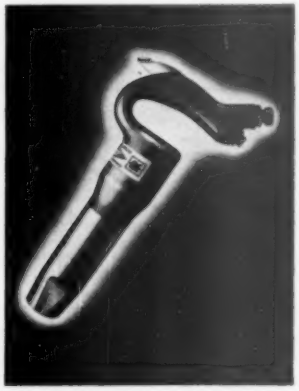


The list price of Model PF Center-Finder is $13.50, and may be ordered direct from Interstate Sales Co., 123 E. 18th St., New York 3, N. Y.

Controlled Power Chipping Hammers

A line of chipping hammers based on a new design to meet the exacting cutting conditions imposed by present-day metals has been announced by Ingersoll-Rand Co. of New York. Known as the Controlled Power Chipping Hammer line, it has an exceptional performance range and offers a selection of 15 power sizes (with 5 basic hammer sizes) to meet the requirements of every job. Each basic hammer size is available in normal-cut, extra-cut or super-cut type, which is made possible by a design variation in one part interchangeable throughout the whole line.

Through the new hard-surfacing Iramet process used exclusively by Ingersoll-Rand, piston life has been increased 12.3 times. Other important parts of Controlled Power Chipping Hammers subjected to wear are also plated with Iramet to give the tools extra-long, trouble-free life. The new Airite valve accurately proportions the amount of air fed to the front and rear of the piston to maintain top cutting efficiency under all conditions, provides a smooth flow of full power and eliminates short stroking and loss of power on heavy cuts.



Ingersoll-Rand controlled Power chipping hammer

IMPORTANT NOTICE!

In mailing the December 1949 issue of The Welding Journal, a box of envelopes was lost. Later on, when found, the November Journals were inserted in error in these envelopes. Therefore, some members will have received two copies of the November 1949 and none of the December. If you are one of these unfortunates, please return the second copy of the November issue to us and advise in regard to the non-receipt of the December number and copy of the December issue will be mailed to you promptly.

The Society is badly in need of these November 1949 issues of The Welding Journal. Therefore, if some members no longer have need for their November Journal, it will help if it is returned to the Society.

AMERICAN WELDING SOCIETY

33 West 39th Street

New York 18, N. Y.

FOR MAXIMUM RESULTS AT THE LOWEST COST!

● In these days when cost has so much to do with the profit you can make, you will do best on welding, cutting or safety equipment by checking with Burdox first! Typical of the outstanding values and superior quality of the entire BURDOX line are six items shown below. Feature for feature, they give you savings at the start and in length of service as well. Get acquainted with BURDOX value by writing for free 64 page catalog today.

CYLINDER TRUCKS

DELUXE MODEL

The greatest cylinder truck value you've ever seen! Streamlined one-piece safety handle. Streamlined tool tray and rack. Bicycle type wheels with solid rubber tires. All welded construction. Chain holds cylinders securely.

JUNIOR MODEL

Ideal for handling small size cylinders! All welded tubular construction, mechanical rubber tires, oilless bronze bearings. Rolls like a charm. Adjustable telescoping tubular device holds cylinders securely.

EYEGARD GOGGLES

The best goggle value on the market! Super-light, impact-resisting plastic and exclusive 10-way ventilation. Cool and sweat-free . . . always!

BURDOX A-C ARC WELDERS

(150-200-250 amp. types)

● A whiz for work. Easy to operate. Weld up to 35% faster. Weld in any position. Shipped with accessories at a real saving!

EXTRA-FLEX CABLE

Extra-flexible, extra-resistance to abrasion, oil and water because of special construction. Millions of feet sold because of performance and price.

CYLINDER CONNECTIONS

● All brass, made to close tolerances, to do the job as only welding men know it should be done. Guaranteed against mechanical defects. Finest made, save time and money, yet cost no more.

THE BURDOX LINE INCLUDES:

WELDING AND CUTTING EQUIPMENT AND MACHINES • SOLDERING AND BRAZING OUTFITS • INDUSTRIAL GASES • REGULATORS AND GAUGES • HOSE AND CABLE • ACETYLENE GENERATORS • GOGGLES AND HELMETS • LENSES AND FACE SHIELDS • ROD AND FLUXES • CYLINDER TRUCKS

THE BURDETT OXYGEN COMPANY

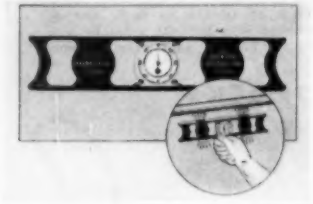
3323 LAKESIDE AVENUE GENERAL ELECTRIC CLEVELAND 14, OHIO

Magno-Level

The Magno-Level, perfected by The Buckeye Plastic Corp., 740 Superior Ave., N. W., Cleveland, Ohio, uses the slogan "It Sticks to the Job" for its combination level and angle indicator.

You think you are seeing a trick of magic when you see the Magno-Level sticking like a leech to a pipe or any other piece of ferrous metal. This new product, a magnetized level, is ideal for steam fitters, plumbers, welders, sheet metal, construction and maintenance workers.

The Magno-Level is equipped with powerful Alnico permanent magnets, sticks to either round or flat surfaces at any angle, leaving both hands free for line-up, straightening or fastening work in place. It has a clock-faced angle gage with



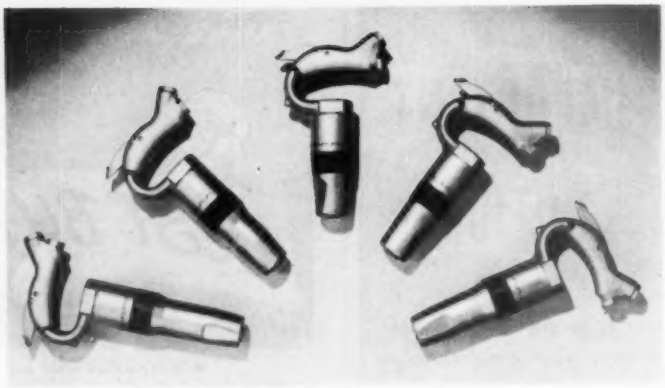
balanced gravity needle, rotating on jewel bearings, which immediately and accurately determines any angle from zero to 360°.

The frame is a special alloy aluminum of high tensile strength with black wrinkle finish, equipped with abuse-proof plastic windows. It comes in a convenient mechanic's pocket-size, measuring 9 x 2 in., and weighs only 10 oz. List price is $5.95, f.o.b. Cleveland, Ohio.

Hard-Facing Electrode

A protected arc electrode to be used primarily for the position of build-up of caterpillar tracks and other equipment that requires building up before final application of Mir-O-Col No. 2, 3 or 1. Particularly good as a hard-facing deposit where glancing blows are experienced or suddenly applied along the edge which tends to break off pieces of the harder deposits. Hardness of deposit 25 to 30, Rockwell C will work-harden to a 45–50 Rockwell C when either peened or subjected to impact. Ideally suited for railroad rails, for the first layer on manganese dipper teeth or manganese parts. Especially suited for anything difficult to hard face because of galling or spalling. The weldability and ease of application of Mir-O-Col No. 4 is outstanding.

Procedure: Straight polarity (electrode negative) d. c. Also good results are obtained by using a.-c. equipment. Best results will be obtained if the weaving motion is held to $1^1/_2$ in. or less to avoid local overheating. The technique is nearly identical to that of ordinary mild-steel welding. To be used flat, vertical or overhead position. Electric Only—a. c. or d. c. Manufactured by Mir-O-Col Alloy Co., Inc., 312 North Ave., 21, Los Angeles 31, Calif.



Chipping Hammers

The Rotor Tool Co., of Cleveland, announces a complete new line of 15 "Multi-Power" Chipping Hammers. These hammers provide 15 different combinations of speed, stroke and blow, giving the user a wide range of hammer performance from which to select the chipper best suited for his job.

The entire line of 15 "Multi-Power" Chippers is based on five basic models, C-10, C-15, C-20, C-25 and C-30. These model numbers refer to 1-, $1^1/_2$-, 2-, $2^1/_2$- and 3-in. piston stroke, respectively. Each of these five basic sizes is adjustable to three combinations of speed and blow by a simple and unique modification. The manufacturer advises patents are pending and that this is the most unique improvement in chipping hammer design from the viewpoint of the user in the past decade. All 15 sizes are equally productive from the standpoint of cutting efficiency through the entire range of speeds, blows and strokes. This gives the user the opportunity to select the right tool for the job under today's conditions of hig[h]-tensile strengths in cast iron, new alloys, in steel and the lighter and stronger metals being used for welding.

Hobart Electro-Mizer

A new product of the Hobart Brothers Co., Troy, Ohio, is the Electro-Mizer which provides greater efficiency and economy to welding operations.

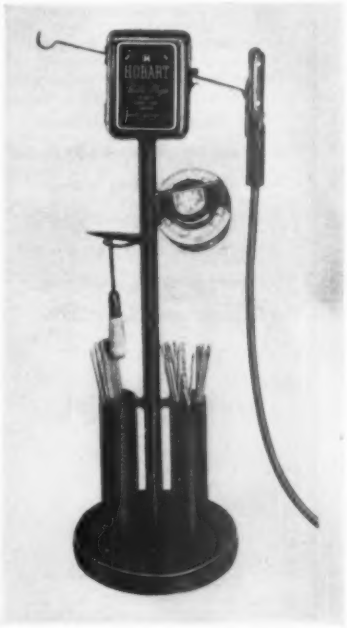
It is a remote Start-Stop switch (mounted on a stand) with arms providing finger-touch control. The weight of an electrode holder breaks the circuit and shuts off the welding machine. It works like this: When you hang up the electrode holder, it automatically shuts off the arc-welding machine, and when you again pick up the electrode holder, it automatically starts the arc-welding machine. Thus, the machine only runs when welding is being done. It can be connected to any motor-generator welder having push button starting.

In addition to the electrode holder, it provides a convenient place for a remote-control rheostat, electrodes, chipping hammer, wire brush, etc.

Soldering Guns

Soldering guns made by Weller Mfg. Co., of Easton, Pa., are newly equipped with rugged housings molded by Weller from one of General Electric Co. Chemical Department's new Hycar-phenolic molding powders. The housing, according to Weller, minimizes breakage, which often occurs in shipment and rough handling by the user, and costs less to make than conventional housings.

The Weller soldering gun is a complete, self-contained unit with built-in transmitter. Its principal advantages are five-second heating to soldering temperature and built-in spot light to illuminate the work. Four models are manufactured ranging from 100 w. for general light-duty service to 250 w. for heavy duty.



abstracts of
CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington, D. C.

2,488,899—Method and Apparatus for Flash Butt Welding—Joseph H. Cooper and Clyde E. Smith, Warren, Ohio, assignors to The Taylor-Winfield Corp., Warren, Ohio, a corporation of Ohio.

The welding method disclosed in this patent covers flash-butt welding of wide thin sections wherein initially a high alternating current voltage is applied to the sections to flash off irregularities in the adjacent edges of the sections. Thereafter the effective value of the current is reduced during the flashing period by reducing the portions of the consecutive half cycles of the current source that are transmitted to the sections to be welded together.

2,489,002—Method of Electric Arc Welding — Charles Albert Babbitt, South Gate, Calif., assignor by mesne assignments to Consolidated Western Steel Corp., Los Angeles, Calif.

This welding method provides seams between adjacent metal plate edges and includes the step of causing relative movement between a direct-current arc and the plate edges, which movement is in a direction longitudinally of the plate edges. The direct-current arc is followed up very closely with an alternating current arc so that the alternating current arc blows, by its magnetic field, the direct-current arc to a leading position.

2,489,224—Apparatus for Seam Welding Elbows—Edwin A. Mellett and Roy W. Pearson, Warren, Ohio, assignors to The Taylor-Winfield Corp., Warren, Ohio, a corporation of Ohio.

The apparatus covered by this patent relates to an attachment for an electric resistance seam welder that has a rotary electrode and a current-conductive support spaced therefrom. The attachment specially equips the apparatus to weld curved surfaces such as elbows.

2,489,475—Magnetic Welder's Ground Clamp—Karl A. Blind, Thiensville, Wis., assignor to Dings Magnetic Separator Co., Milwaukee, Wis., a corporation of Wisconsin.

This patent covers a special magnetic clamp especially usable as a welder's ground clamp.

2,489,992—Welding Electrode Holder—Norman Albert Tucker, London, England, assignor to P. R. Mallory & Co., Inc.

Tucker's electrode holder comprises a shank having a longitudinal passage extending therethrough and having a socket for receiving a welding electrode at one end of such passage. A cooling fluid conduit extends through the passage in the shank and is spaced from and in positive gripping engagement with the shank interiorly of same at definite points only therein.

2,489,993—Offset Resistance Welding Electrode with Coolant Tube—Arthur F. Wood, Indianapolis, Ind., assignor to P. R. Mallory & Co., Inc., Indianapolis, Inc., a corporation of Delaware.

Wood's special type of electrode includes an offset welding electrode tip that has a spaced portion adapted to be seated in the socket of a welding electrode holder. The tip also has a curved portion and a nose portion including a welding face. The tip has a bore formed therein which extends therethrough into the nose portion and a cooling fluid conduit is mounted in the bore, extending into the nose portion of the tip.

2,489,994—Welding Metallic Tips to Bases—Norman Albert Tucker, and John Ernest Wall, London, England, assignors to Johnson, Matthey, & Co., Ltd., London, England, a British company.

The patented welding apparatus includes a rotatable turret, at least one base-holding device on the turret, and a displaceable tip-supporting device and a base-withdrawing means associated with the turret and arranged externally of and at spaced portions around the periphery of the turret. A welding circuit includes the base-holding device and the tip-supporting device. Common operating means are provided for moving the base-holding device progressively to each of the positions in turn and for effecting displacement of the tip-supporting device when the base-holding device reaches a position to bring a tip carried by the support into contact with the base and close the welding circuit.

2,490,023—Welding Electrode—Arthur A. Bernard, Chicago, Ill., assignor to National Cylinder Gas Co., a corporation of Delaware.

Bernard's welding electrode is a flexible one for producing an inverted crucible type of arc. The electrode has a metal core with a plurality of substantially continuous ribs and a metal wire is spirally wound around on said core in contact with the ribs. A coating of flux material encases the core and fills the spaces defined by the ribs and also the spaces defined by the winding. The metal wire is exposed on the surface thereof to form a conducting path for the welding current from the surface thereof to the metal core.

2,490,024—Automatic Arc Welding Apparatus—Arthur A. Bernard, Chicago, Ill., assignor to National Cylinder Gas Co., a corporation of Delaware.

This welding machine includes a frame that has means for moving the work along a line relative to the frame. Power-driven feed rolls are provided for feeding the continuous electrode wire to the work and a welding head is mounted on the frame and has the electrode passing therethrough. Contact jaws are provided for passage of the electrode wire therethrough and for feeding current to the electrode. These jaws are rotatable with respect to the line of movement of the work so that the electrode may be held in different position of rotation to lay down welds of different widths.

2,490,119—Gas Cutting Apparatus for Serrating Metal—Fred Stanley Edinger, Alameda, Calif., assignor to Air Reduction Co., Inc., a corporation of New York.

This apparatus included a wheeled torch carriage that travels over workpieces and the torch will cut a serrated kerf in the workpiece which continually moves with relation to the carriage.

2,490,153—Weld Holder—James J. O'Donnel, Somerville, Mass., assignor of one-half to Arthur L. McAvoy, Arlington, Mass.

This weld rod holder relates to a tool for use in holding an electric weld rod in position. A handle is provided on the tool and it has a loop of substantially nonyieldable metallic material attached to the handle at one portion thereof. The loop has side arms that converge in and join together to close the loop adjacent the end of the handle from which the loop extends.

2,490,179—Method of Electric Arc Welding—Paul Christiaan van der Willigen, Simon Dirk Boon and Johannes Hollerhoek, Eindhoven, Netherlands, assignors to Hartford National Bank and Trust Co., Hartford, Conn., as trustee.

In this welding method, the weld rod has an iron core which is provided with a special coating composition. The external diameter of the weld rod exceeds 1.175 times the core diameter and is approximately twice the thickness of thin iron sheets to be welded thereby.

2,490,871—Alternating Current Vertical Welder—Edward A. Hobart and Russell T. Flora, Troy, Ohio, assignors to The Hobart Brothers Co., Troy, Ohio, a corporation of Ohio.

The welding transformer of this patent includes a pair of relatively movable coils and an indicator dial is provided and has a fixed indicator means associated therewith. An eccentrically shaped pulley is fixed to rotate with the dial and has a cable attached thereto and operating over the eccentrical portion of the pulley and connected to one of the coils. Resilient means normally rotate the dial and the eccentrically shaped pulley to maintain the cable under tension and effect a nonuniform relative rotation of the dial.

2,491,169 — Large Throat Portable Welder—Harold C. Early, Beaverton, and Wm. G. Dow, Ann Arbor, Mich., assignors to General Motors Corp., Detroit, Mich., a corporation of Delaware.

This patent relates to a transformer wherein a primary winding has substantially a rectangular turn configuration with one part bent back to lie in noninductive relation to the other. A secondary winding of the approximate size and configuration of the first part of the primary and mounted in close proximity thereto is provided so that there will be a high mutual inductance coupling between the secondary and that part of the primary adjacent thereto. Substantially no flux interlinkage exists with the other parts of the primary and the secondary winding.

2,491,319—Automatic Arc Welding Device—Hermann Kocher, Engstringer, near Zurich, Switzerland, assignor to Aktiengesellschaft Brown, Boveri & Cie, Baden Switzerland, a joint-stock company.

In this device, a feed motor is provided for feeding an electrode toward a workpiece as the electrode is consumed and automatic means are provided for controlling the speed of the feed motor to maintain a substantially constant arc potential. The feed motor controlling means include a direct current generator having main and auxiliary field windings each arranged for external excitation. Means are provided to drive the generator at a substantially constant speed and means supply the main winding with a substantially constant energization potential. Additional means are provided to produce a substantially constant counter potential and circuit means arrange the auxiliary generator field windings for energization in accordance with the instantaneous difference between the counter and arc potentials. The direction of current flow through the auxiliary field winding is determined by the sense of the difference between the potentials.

2,491,413—Welding Controller—Geo. J. Lexa, Wauwatosa, Wis., assignor to Cutler-Hammer, Inc., Milwaukee, Wis., a corporation of Delaware.

This welding patent relates to a system in combination with an ignitron which has an alternating current supply connected to its main electrodes and welding electrodes are connected to and derive welding energy from the supply as a function of discharge of the ignitron. The control includes various electrical devices and an electro-magnetic relay which is in circuit with the current supply to the main electrodes of the tube and responsive to abnormal conditions in a unidirectional biasing source to interrupt the current supply to the main electrodes of the ignitron tube.

2,491,440—Woodrow S. Boedecker, Prince Bay, N. Y., and Lansing N. Hinrichs, Wilmette, Ill,, assignors to The Bastian-Blessing Co., Chicago, Ill., a corporation of Illinois.

Boedecker's patent is on a cutting blowpipe tip wherein a central passage is provided and a plurality of passages are provided substantially parallel to the central passage and have an inclined annular passage that connects the plurality of passages with the central passage.

2,491,479—Arc Welding of Studs—Edward Dash, Long Beach, Calif.

This patent relates to a welding method wherein a stud of a special composition is welded to a member composed at least of 75% aluminum. The stud is primarily made from aluminum and includes between 4.5 and 6% of silicon and small amounts of other ingredients.

2,491,563—Apparatus for Cutting Metal—Howard G. Hughey, Fanwood, N. J., assignor to Air Reduction Co., Inc., a corporation of New York.

This patent relates to a gas-cutting torch which has tip means for providing preheating flames and a cutting oxygen jet. Auxiliary means are positioned between the torch tip and the workpiece for directing at least one heating flame toward and against the jet of cutting oxygen after it leaves the torch tip and before it reaches the workpiece.

2,491,946—Electrode Holding Device—Richard E. Ballentine, Snyder, and Frederick V. Schilling, Buffalo, N. Y., assignors to Westinghouse Electric Corp., East Pittsburgh, Pa., a corporation of Pennsylvania.

This patent relates to an arc torch which includes a handle with a rigid conductor projecting therefrom and a holder for the electrode supported by the rigid conductor. Special lever support means are also provided as is a wheel having an eccentric connection with the lever adjacent an end thereof and rotatably supported on the handle of the device.

LIST OF NEW MEMBERS

December 1 to December 31, 1949

BOSTON

Brown, F. C. (B)
Graham, Chester (C)
Graham, Robert (C)
Hall, Frank E. (C)

CHICAGO

Barnett, Nelson D. (B)
Lines, Harold G. (B)
Szymko, Chester T. (C)

CINCINNATI

Foote, Edward L. (C)

CLEVELAND

Gunnesh, Robert M. (B)

COLUMBUS

Keyser, William Boyd (D)
Romance, Wasil, Jr. (D)
Shira, Chester Sterling (D)

DALLAS

Irons, J. D. (B)
Thomas, Irvis L. (C)
Warren, Edward L. (B)

DAYTON

Arnold, Robert E., Sr. (C)
Dane, Paul E. (C)

DETROIT

Barron, Hugh (C)
Bruen, T. E. (C)
Buhler, Charles G. (B)
Carlos, Richard Don (B)
Chapman, Charles S., Jr. (D)
De Podesta, Frank (B)
Dietz, Otto E. (C)
Diosi, Frank (C)
Drissen, W. W. (B)
Ford, Eugene R. (A)
Gunttonin, Wayne (C)
Hinds, Spencer C. (B)
Hufert, T. L. (C)
Humitz, Steven (C)
Huysentruyt, George (C)
Kelley, Robert M. (B)
Kiilunen, Matt (C)
Maas, Larry (B)
McDonough, L. J. (A)
Meyers, Albert (C)
Miller, Edward (C)
Miller, Roland (C)
Minore, William (D)
Nater, Jack (C)

Nelson, Robert J. (B)
Ouellette, L. C. (B)
Pah, George (C)
Polagyi, Steve (C)
Powder, Paul (C)
Rockafellow, Stuart C. (B)
Schamanek, Charles (B)
Sirey, William, Sr. (C)
Sloan, George W. (B)
Stewart, Alan (C)
Sypula, Frank W. (B)
Yokum, John (B)

HARTFORD

Duval, L. E. (B)
Gallo, Francis (B)
Ponte, Paul (C)
Pulcini, Anthony (C)
Wesley, Charles B., Jr. (C)

HOUSTON

Davis, Robert Emmett (C)
Lindquist, Robert C. (B)
Looney, Edward T. (C)

INDIANA

Christison, Herman R. (C)

KANSAS CITY

Browning, A. H. (C)

LEHIGH VALLEY

Hooper, George R. (C)
Strauss, Chester H., Jr. (C)

LOS ANGELES

Forsyth, Donald P. (C)
Galarneau, John R. (C)
Greene, William A. (C)

MAHONING VALLEY

Reno, C. Dealvy (B)
U'Halie, N. G. (B)

MARYLAND

Baker, Thomas R. (C)
Landrum, Wm. C. (C)

MILWAUKEE

Dobeus, J. R. (C)
Gulczynski, Peter Paul (C)

NEW YORK

Cordovi, M. A. (B)
Urucinitz, George (B)
Weiskopf, Walter H. (B)

NORTHERN NEW YORK

Cappelletti, Albert L. (D)
Lagrange, Pierre D. (C)
Philipps, Edward J. (D)

NORTHWEST

Schardin, Harold E. (C)

OKLAHOMA CITY

Dodderer, Fred (D)
Maxey, William S. (D)

RICHMOND

Adcock, Aubrey A. (B)
Anderson, Linwood B. (C)
Bailey, Richard C. (C)
Calder, Vaughan E., Jr. (C)
Canning, Raymond John (C)
Collier, William C. (B)
Cruickshanks, Douglas (B)
Dillard, Charles G. (C)
Donnelly, J. S. (C)
Femiani, G. Joseph (C)
Fulton, John L. (C)
Godfuit, Ralph C. (C)
Goff, Jacob M. (C)
Goode, W. B. (C)
Haile, Edwin C. (C)
Hickman, Paul (B)
Howe, D. E. (C)
Hudgins, Terrell W. (C)
Jones, W. B. (C)
Kemper, G. G. (C)
Kramer, Leo A. (B)
Lassiter, Melvin Vance, Jr. (C)
Lawrence, L. M. (B)
Lewis, Claude Robert (C)
Lough, Jack S. (C)
McDearmon, George G. (C)
McLauchlan, J. Stuart (B)
Mayers, David (C)
Mayers, Fred T. (C)
Meeks, Wallace E. (C)
Miller, Vernon E. (C)
Mitchell, C. Lawrence (B)
Morris, J. A. (C)
Nissley, James Edward, Jr. (C)
O'Brien, Haskell H. (B)
O'Brien, W. C. (B)
Otey, M. R. (B)
Potts, E. C. (C)
Powell, Alvin W. (C)
Richman, John A. (C)
Ross, Boyd J. (C)
Schrader, Norman R. (B)
Scott, David D. (C)
Shelton, Jack (C)
Sydnor, Garland S. (C)
Thomas, W. Randolph (B)
Thornhill, Arthur M. (C)
Thurston, M. C. (B)
Tuck, T. W. (C)
Turner, H. C. (C)
Watkins, George B. (C)
Williams, Chas. L. (B)
Wilson, George B. (C)

ROCHESTER

Adams, Charles R. (C)
Martin, C. K. (C)

SAGINAW VALLEY

Brodrick, Lawrence, J. (D)
DuBois, Lawrence W. (D)
Fencl, Vernon R. (D)
Green, Gordon R. (D)
Grillmeier, Earl, Jr. (D)
Hall, Edward C. (C)
Kahn, Pedro A. (D)
Krichbaum, Hans J. (D)
McKeel, George J. (D)
Porter, George H. (D)
Schneider, Ed (D)

ST. LOUIS

Graves, Keith E. (C)
Johnson, O. K. (C)

SALT LAKE CITY

Wilkins, W. E. (B)

SAN FRANCISCO

de la Vergne, George H. (B)
Kallin, Erik (C)

SUSQUEHANNA VALLEY

Hewitt, John M. (C)

SYRACUSE

Chemerys, Joseph J. (C)

TOLEDO

Ostrosky, Carl F. (B)

WESTERN MASSACHUSETTS

Gutowski, Walter A. (B)

WORCESTER

Baum, John E. (B)

NOT IN SECTIONS

Bose, Edward Mahendra Lal (B)
Gardner, E. P. S. (B)
Heafield, Cyril (B)
Miller, Hugh, (C)
Tsukui, Matsutaro (B)
Way, Clarence (C)
Yohe, Robert Engle (B)

Members Reclassified

During the Month of December

MAHONING VALLEY

Jennings, J. Carroll (C to A)

NEW JERSEY

Frank, Jacob (C to B)

NEW YORK

Rockefeller, Harry E. (B to A)

SECTION ACTIVITIES

prepared by C. M. O'Leary

Anthony Wayne

The December meeting of the Anthony Wayne Section was in the form of a Christmas Party for members, guests and their wives. The party was held on the 19th in the auditorium of the Fort Wayne Chamber of Commerce Bldg., Fort Wayne, Ind.

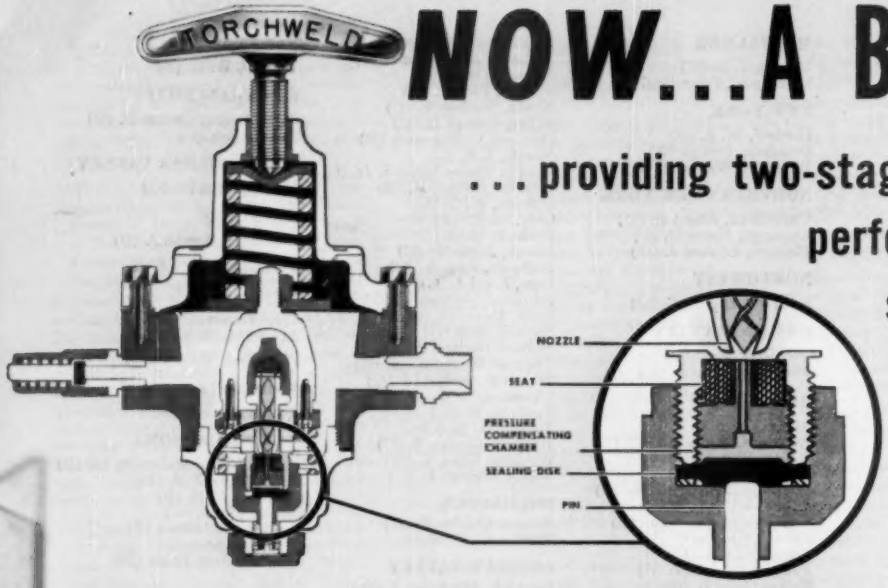
Festivities began at 6:30 P.M. when those present gathered around the punch bowls and trays of canapes in the beautiful outer lunge which had been decorated in keeping with the yuletide season. Dinner was served at 7:30 P.M. From 8:30 to 10:00 P.M. the gathering was highly entertained by Prof. Eiffel Plasterer and his "Bubbles Concerto." He has a most unique and marvelous exhibition on the blowing of ordinary soap bubbles which is reported to be the only thing of its kind in the United States and probably the world. With an immense amount of equipment which took two and one-half hours to set up he showed conclusively that the blowing of bubbles was not mere child's play. Using his own breath, hydrogen and oxygen he made soap bubbles that arose like balloons with "gondola"-like attachments hanging below. He encased a woman in one shimmering soap bubble, exploded other bubbles like bombs, made them perform magic tricks, used them for demonstrating scientific laws relative to pressure changes and sound waves, blew them by using the heat of his hands, and many other phenomenal exhibitions that gave those present a most enjoyable hour and a half. Dancing then followed until 12 o'clock. Forty couples attended the party.

Arizona

The regular monthly meeting of the Arizona Section was held in the Aluminum Room of the Westward Ho Hotel on the evening of December 21st. Approximately forty people were present. Walt Wiley, Technical Advisor, talked on the technical activities of the SOCIETY and explained to the members how they could use these facilities. The Chairman, Ralph Hoffman, gave a delightful and instructive talk on the welded steel arch bridge at Clear Creek Canyon in Arizona. Mr. Hoffman is Superintendent of Bridge Construction for the State of Arizona. Two films were then shown, one on the working of magnesium by the Dow Chemical Co., and the other purely for pleasure, Arizona in technicolor.

NOW...A BRAND

...providing two-stage regulator performance for single-stage regulator cost!



Here's why Torchweld "6500" delivers constant pressure and volume regardless of drop in cylinder pressure

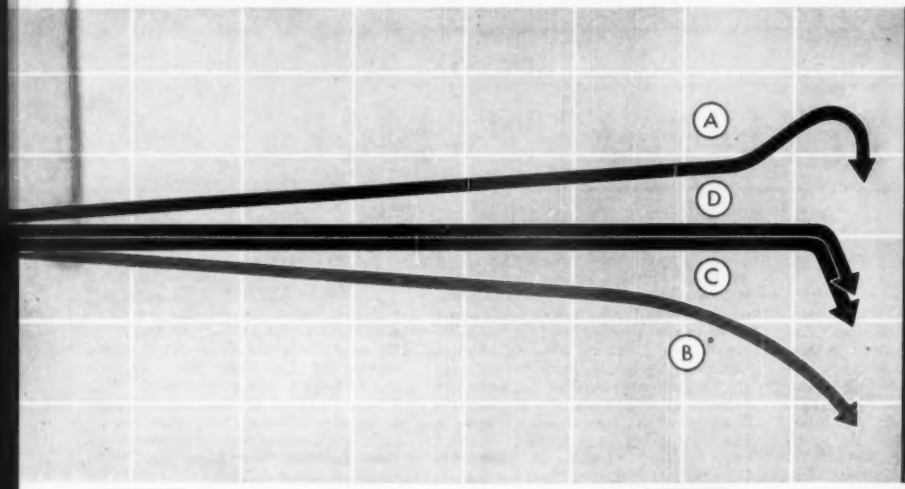
In any regulator the pressure of the incoming gas is one of the forces operating the valve mechanism. As cylinder pressure drops, this force decreases, causing a variation in the volume of gas flowing through the valve.

In the TORCHWELD "6500," a pressure compensating chamber below the seat counteracts the effect of this decreasing force.

A small passage in the valve seat permits gas *at cylinder pressure* to enter the chamber. At the bottom of the chamber is a reinforced rubber sealing disk. Below the disk is a pin which rests against the back of the regulator

The forces within the chamber act upon the disk and pin so that there is a resultant effective force which tends to move the seat upward toward the nozzle.

As cylinder pressure drops this upward force diminishes, resulting in a gradual increase of the spacing between seat and nozzle. This compensates for the effects of decreasing cylinder pressures, and thus maintains constant delivery pressure and volume.



Here's how various types of regulators act as cylinder pressure drops

A TYPE —*Stem-type* single-stage regulator delivers at *increasingly higher* pressures as the cylinder empties. Frequent pressure adjustments are necessary.

B TYPE —*Nozzle-type* single-stage regulator delivers gas at pressures that *drop lower and lower* as the cylinder empties. Frequent pressure adjustments are necessary.

C TYPE —*Two-Stage* regulator gives uniform working pressure regardless of cylinder pressure, depending upon quality of regulator. Pressure adjustments are avoided.

D TYPE —TORCHWELD "6500" REGULATOR delivers *constant* working pressure (whatever it's set for) regardless of drop in cylinder pressure. No adjustments are necessary while welding or cutting.

NEW TYPE OF REGULATOR

FIRST, in the early days of welding and cutting, came the single-stage regulator.

THEN, about 20 years ago, came an important improvement—the two-stage regulator.

NOW, comes an even greater development—the new NCG TORCHWELD "6500" regulator.

TORCHWELD "6500"

REGULATOR WITH PRESSURE COMPENSATING CHAMBER

The first major advance in regulator design in 20 years

Now you can have the precise pressure control heretofore available only in high-priced two-stage regulators for the low cost of a single-stage regulator. Now, thanks to NCG research and design, you can have a regulator that combines the best features of these *two* earlier types.

The new, unique TORCHWELD "6500" gives you precise and *constant* working pressure and volume (at whatever setting you choose) *regardless of drop in cylinder pressure.* In addition, you get all the economy advantages typical of the single-stage regulator.

The explanation lies in the NCG-engineered "pressure compensating chamber," an exclusive TORCHWELD feature—the first major advance in regulator design in 20 years. Further, the "6500" has extra-big streamlined gas passages for ample volume, the exclusive "SPIREX" nozzle element that prevents seat ignition, an inlet filter, relief valve, rugged construction and few working parts to wear or repair.

Yet, the TORCHWELD "6500" is priced only slightly above the average single-stage regulator. No wonder it is being acclaimed the greatest value ever offered! For more details, write for Illustrated Bulletin No. NTW-104 and price list.

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Boston

The November 14th meeting of the Boston Section was held at Graduate House, M.I.T., Cambridge, Mass. Dinner was held in the Fabyan Room, with an attendance of forty-four at dinner and fifty-nine at the meeting. Dinner speaker was Walter Ovaska of Air Reduction Sales Co., Boston, who gave an interesting talk, illustrated with Kodachrome slides, of a trip to Finland. Technical speaker was George Richardson of the General Electric Co., Lynn, Mass., whose subject "The Welding of Jet Engine Components" was illustrated with slides and movies. This meeting was called a Home Talent Meeting as both speakers have been very active members of the Section; both having served on the Executive Committee several times, with Mr. Ovaska as Secretary-Treasurer last year.

The December 12th meeting was held in Graduate House, M.I.T., Cambridge, with an attendance of sixty. Dinner in the Campus Room was served to fifty-two members. Because of illness the coffee speaker could not attend. In his place a Boston and Maine R.R. colored moving picture, "Summer in New England," was presented. Technical speaker was Frederick H. Diller, Welding Engineer for the American Bridge Co. His subject, "Economics of Structural Welding," was illustrated with slides and very well received. The Section was honored with the presence of C. I. MacGuffie, a Director of the Society, who came down from Fitchburg to attend the meeting and gave a very interesting talk on some of the subjects under discussion at the Directors' meetings.

Chicago

A "Quiz-the-Experts" program was the feature of the November 18th meeting of the Chicago Section held in the auditorium of the Peoples Gas Light & Coke Co. Three teams representing Indiana, Milwaukee and Peoria participated. Questions used were previously submitted by many individuals and were properly edited. Subjects covered were Arc, Gas, Resistance, Metallurgy and Research. Each team was asked a similar question in the various groups. If, in the opinion of the judges, the question was not completely or correctly answered, other teams were allowed to take the question if the first team's answer was not correct or to elaborate if the previous answer was not complete. Quickie questions carried less points as announced by the moderator. Ten points were allowed for a complete answer. The final standing was Indiana the winner, Milwaukee second and Peoria third. A parlor was obtained at the Congress Hotel where the teams met before dinner and were introduced. The teams were dinner guests of the Chicago Section at Burke's Grill. It was a good meeting and enjoyed by all.

An excellent meeting was held on December 16th in the auditorium of the Peoples Gas Light & Coke Co. Dinner at Burke's Grill preceded the meeting. A premeeting movie on the subject of Bowling was shown. Technical speaker was John Randall of the Ford Motor Co., Dearborn, Mich. Mr. Randall presented an illustrated talk on "Welding Applications in Automotive Construction."

Cleveland

The December dinner meeting of the Cleveland Section was held on the 14th at the Cleveland Engineering Society. Dinner speaker was Barring Coughlin, a Cleveland attorney, who gave a very interesting talk on "A Practical Program for Peace." Technical speaker was C. B. Voldrich, of Battelle Memorial Institute, whose illustrated remarks on "Inert Gas-Shielded Arc Welding" were extremely beneficial. A Past-Chairman's pin was presented to M. S. Shane by K. C. Thornton.

Colorado

The December 13th dinner meeting of the Colorado Section was held at Silver Wing Inn, Denver, Col. Carl G. Borgeson, Chemical Engineer, Gardner-Denver Co., gave a very interesting and clear talk, illustrated by slides, on "Magnet Particle Inspection of Welds." Following the technical session two films were shown: "Industry in Sweden" and "Behind Your Radio Dial."

Columbus

W. W. Reddie, Assistant Manager, Arc Welding Dept., Westinghouse Electric Corp., was the guest speaker at the December 9th dinner meeting held at the Fort Hayes Hotel, Columbus, Ohio. Mr. Reddie's subject was "Safe Practice in Electric Arc Welding." This lecture was important inasmuch as it explained the safety factors to practice in a.-c. welding. Many of the safety practices used extensively in other types of work are ignored in welding. Mr. Reddie stressed the value of a safety program for welding.

Dallas

W. H. Greer of Southwestern Laboratories presented a good, clear-cut talk on "Arc Welding at Work" at the December 21st meeting held in the auditorium of the Mercantile National Bank, Dallas, Tex. Dinner preceded the meeting at the Town and Country Restaurant. Slides are used illustrating various methods and problems encountered in arc-welding structural steel in tall buildings. A color, sound film, "Arc Welding at Work," was shown in conjunction with Mr. Greer's talk.

Detroit

The honoring and recognition of its past-chairmen was the high point of the December meeting, "Past Chairmen's Night," held on Dec. 9, 1949. Celebrated also on this gala occasion was the 25th birthday of the Section. Held in the main ball room of the Wardell Sheraton Hotel and attended by 180 members who came to do honor to their past chairmen, the evening's festivities were started with a dinner for the past chairmen.

The present Chairman, Thomas J. Crawford, drew a word picture of the important part taken by each past chairman in guiding the progress and growth of the Section to national recognition and service and pointed to the goal still ahead. The following past chairmen were then introduced: W. M. Hayes, 1935–36; J. O. Tebben, 1936–37; V. Reid, 1937–38; D. H. Corey, 1938–39; H. P. Doud, 1939–40; G. N. Sieger, 1940–41; J. R. Stitt, 1948–49; O. L. Smith, 1942–43; E. H. Foss, 1943–44; H. C. Neitzel, 1944–45; G. J. Friebel, 1945–46; A. H. Lewis, 1946–47; and A. J. Last, 1947–48.

The guest speaker of the evening, Dr. David D. Henry, President of Wayne University, nationally known educator and prominently active in civic affairs, spoke on the need and progress of adult education as geared to modern day thought and trends.

Immediately following a talented group of artists provided an hour of wonderful entertainment enjoyed by all. Then

came the social get-together of intimate groups and conversational reminiscing. Ample refreshments were on hand to further enliven the occasion, furnished by the generosity of the patrons-list members.

A night to be long remembered—many thanks to the program chairman, Ed Brown and his committee.

Hartford

Dinner meeting of the Hartford Section was held on Thursday, Dec. 8, 1949, at The Rockledge Country Club, West Hartford, Conn. Dr. Vincent T. Malcolm, Metallurgist of Chapman Valve Co., spoke on "New Welding Techniques and Procedures." Two associates of Dr. Malcolm's helped in the question period.

Louisville

Van Rensselaer P. Saxe, Consulting Engineer of Baltimore, Md., was the guest speaker at the Nov. 22, 1949, meeting. Mr. Saxe presented an illustrated talk on some interesting welded structures. A movie film, "Atomic Power," was also shown. A social hour and lunch took place at the close of the meeting.

Mahoning Valley

A talk on "Check Your Maintenance Welding" was very ably presented by Lew Gilbert, Editor of Industry and Welding at the Nov. 17, 1949, meeting of the Mahoning Valley Section held in the Ohio Edison Auditorium, Youngstown, Ohio. About fifty were present to hear this interesting talk.

Future meetings of this Section are as follows: March 14th—Joint Meeting with A.I.E.E. "Television" to be presented by an Engineer of the Dumont Corp. April 20th—"Inert Arc Welding and Its Application" to be presented by an Engineer of the General Electric Co.

Michiana

"As much as I would like to be able to say that the best reason for designing a joint to be welded was quality, I would be misleading you if I did. The No. 1 reason is because it is cheaper." So said L. S. McPhee, Welding Engineer of the Whiting Corp., Harvey, Ill., speaking at the December 15th meeting of the Michigan Section on "The Reasons Behind Welded Design." Quality is undoubtedly the second most important reason. Another is the space available in which to put the joint. Mr. McPhee's discourse gave an insight into the number of problems faced by both engineer and welder before satisfactory completed parts can be produced.

Milwaukee

The Milwaukee Section held its December meeting on the 16th, one week early because of the holidays. A buffet supper was served and the coffee talk was omitted.

The technical speaker was H. E. Gannett, of the Burlington Lines, Chicago. Mr. Gannett presented a very interesting talk on "Welding Cast Iron by the Heliarc Process." Slides illustrating the application to Diesel locomotive cylinder heads and pistons were shown. During the course of his talk, Mr. Gannett presented some interesting sidelights on the development of welding on the railroads.

New York

On Dec. 13, 1949, the New York Section was privileged to hear a paper by Howard S. Avery, Research Metallurgist, American Brake Shoe Co., Rahway, N. J., entitled "Hard Facing by Welding."

Speaking before a large and interested audience, Mr. Avery thoroughly covered his subject. He pointed out that the many merits of hard facing stem from the special materials used. Whereas ordinary weld deposits have a hardness ranging up to about 200 Brinell and hardened steels increase the range to around 700 to 800 Vickers, the extremes realized by the special carbides of hard facing alloys extend the hardness range to the vicinity of 3000 Vickers. Mr. Avery indicated that hard facing by fusion welding is a technique that combines the advantages of protection in depth with ease of use of alloys and hard compounds having exceptional wear-resistant properties. Pointing out that hardness does not necessarily correlate with wear resistance, Mr. Avery described some of the special tests of hard facing alloys used to indicate their relative stress abrasion, seizing or galling properties, resistance to oxidation, corrosion and hot wear.

Johannes Erler, Consulting Metallurgist, Farrel-Birmingham Co., Inc., Ansonia, Conn., served admirably as Technical Chairman, introducing the speaker and leading the discussion after the presentation of the paper.

Prior to the technical session, members and their guests were shown a demonstration of the behavior of radio microwaves as used to relay television, radio and telephone communications. Through the courtesy of the New York Telephone Co., A. R. Entwistle gave a stimulating talk and presented a highly entertaining demonstration of microwaves and some of the tricks possible with them in his after-dinner program entitled, "High Waves of Communications."

Details of the meeting were arranged by D. Swan, Associate Member of the Executive Committee. The meeting commenced with dinner at Schwartz's Restaurant, 54 Broad St., New York.

Niagara Frontier

A joint meeting with the Buffalo A.S.M. Chapter was held on December 8th at the Sheraton Hotel, Buffalo, N. Y., with approximately 180 present.

Dinner speaker H. G. Maynor, Federal Bureau of Investigation, spoke on the Organization and Activities of the FBI. An excellent talk and a good speaker, presenting the subject in interesting fashion.

Technical speaker was Dr. Robert H. Aborn, Asst. Dir. of Research, U. S. Steel Corp., Kearny, N. J., whose subject "Recent Aspects of the Metallurgy of Ferrous Welding," covered advancements made to date in studies of weldability of steels in general. Especially mentioned were the effects of alloying elements together with the effects of oxygen, nitrogen and hydrogen.

Initial showing of a film, "Welding Arc Behavior," representing U. S. Steel's first attempt to study arc welding behavior with the high-speed camera (3000 frames per second, 16 mm.) was excellent.

Philadelphia

The December meeting of the Philadelphia Section, despite the disadvantages of falling on the Monday immediately before Christmas, the 19th, maintained the same high caliber that has distinguished the meetings during 1949.

Although Christmas shopping took precedence, with a few members, over the dinner before the meeting, it could not compete with the speaker and subject for the evening. Charles H. Jennings, Manager of Arc Welding Engineering of the Westinghouse Electric Corp., who is also 2nd Vice-President of the SOCIETY, held the interest and attention of those present with his talk and slides on "Machine and Automatic Arc Welding." He thoroughly covered the general considerations and requirements of automatic machine welding in his prepared talk. The interest in this subject was very evident by the lively discussion that followed. The discussion, as usual, continued while the refreshments were being enjoyed.

The panel discussion meeting on "The Welding and Fabrication of Aluminum," which was held on Dec. 7, 1949, again provided an overflow crowd for the Junior Room at The Engineers' Club. The popularity of these panel discussions has been outstanding.

A "Battle of the Sections"—Philadelphia Section vs. Eastern Section—will take place on Mar. 20, 1950, and on Saturday evening, May 27, 1950, there will be a Social Night, Dance and Buffet Supper at The Engineers' Club.

Rochester

Dinner at Guy Michael's Restaurant with approximately twenty present was held on Dec. 19, 1949. Following the dinner a group of approximately forty met in the Engineering Bldg. of the University of Rochester. Before proceeding with the technical lecture a movie entitled "Basketball Thrills of 1949" was shown.

The lecture for the evening was entitled "Resistance Welding," and was given by John E. Ponkow of the Warco Machinery Corp. Mr. Ponkow gave a general discussion of the resistance welding process describing the development of the various processes as well as describing the types of equipment currently available. Mr. Ponkow also outlined a general procedure which could be used to determine the values of current, pressure, etc., when setting up to produce spot welds on sheet steel. Mr. Ponkow used a series of slides as well as movies to illustrate his talk.

In conjunction with Mr. Ponkow's lecture, Russell Staggs, of the Westinghouse Electric Co., spoke briefly on resistance-welding controls and their development.

Mr. Staggs used a series of slides as well as a number of electronic tubes to illustrate his talk. An ignitron tube of early design as well as a modern tube provided a very interesting illustration of the improvements that have been made in tube construction.

Salt Lake City

The Dec. 8, 1949, dinner meeting was held in the Seagull Room, Temple Square Hotel, Salt Lake City, Utah.

"Refinery Welding" was the subject covered by Alexei P. Maradudin, Materials Engineer, Standard Oil Company of California. Mr. Maradudin knew his subject well and his talk was more on the practical than the technical side. However, in the open discussion several questions of a technical nature were asked and Mr. Maradudin answered them quoting chemical compositions of various alloys and recommended fabricating techniques.

Toledo

A joint dinner meeting with O.S.P.E. was held on November 9th in the Crystal Room of the Commodore Perry Hotel, with an attendance of 200 at dinner and 250 at the meeting. Martin P. Korn, Consulting Engineer, presented a clear-cut talk on "Rigid Frames."

The December meeting was held on the 14th in the Toledo Room, Commodore Perry Hotel. J. I. Banash, Consulting Engineer, spoke on "Safety in Welding."

Tri State

Ladies Night was held on Wednesday Dec. 14, 1949, at the Alpine House, Evansville, Ind. R. L. Boone and Mr. Murphy, of Owens-Corning Fiberglass Co., gave a lecture and a display on Fiberglas. It was quite interesting to see what is being accomplished with glass.

Western Massachusetts

Due to the recent transfer and resignation of the Chairman, R. W. Tuthill, and the resignation of the Treasurer, J. W. Flaherty, the Board of Directors of the Western Massachusetts Section recently met and appointed the following officers for the remainder of the year: Carl A. Keyser, *Chairman;* L. W. Jaeger, *Vice-Chairman;* Victor Bissonnette, *Secretary;* and Frank W. Taft, *Treasurer.* The following committee chairmen were also appointed for the balance of the year: C. A. Keyser, *Program Chairman;* F. W. Taft, *Membership Chairman;* L. W. Jaeger, *Publicity Chairman.* The following member was added to the Board of Directors of the Section: Theodore Morrisette.

Members and guests of the Section were entertained at their Annual Christmas Party, following a dinner in The Red Barn Restaurant in Chicopee Falls, on Dec. 6, 1949. Door prizes were donated by Frank Taft of the Taft Welding Equipment Co., and L. W. Jaeger of Jaeger Welding Supply Co., both of Springfield Mass. Irving Clarke, of the Movie Center, showed some newsreels, comedies and selected short subjects, following a short one-man act put on by Dennis O'Brien Healey of Holyoke, Mass. In charge of arrangements for the party was a Committee consisting of Frank W. Taft, L. W. Jaeger and Victor Bissonnette.

Employment Service Bulletin

Services Available

A-594. Capable Welding Foreman. Fifteen years' experience refinery, boiler and tank shops, prefabricated piping and pipe lines.

A-595. Metallurgist, B.S. Ch.E., Purdue University. Ten years' diversified experience in welding metallurgy research, physical testing, heat treatment, quality control. Some experience with high temperature alloys and aluminum. Steel mill experience. Desires position in development, industrial research, or production in Northeast U. S. or midwest. Married. Age 32. Excellent health.

Position Vacant

V-243. Welding Research Chemist Wanted. Creating new position of exceptional interest to a graduate chemist experienced in research, development and manufacture of welding rods and electrodes. This is a permanent position, with unlimited scope for a research and development chemist. Person selected will have a solid background of all phases of oxy-acetylene and arc welding, for ferrous and nonferrous metals.

This progressive company is prepared to put considerable resources behind this position. It offers expanding research facilities, as well as an atmosphere of congeniality, to induce top creative work. Location: Flushing, Long Island, 20 minutes from New York City. Kindly submit a complete transcript of curricular work and subsequent employment. All applications treated in strictest confidence.

(*Continued from page 149*)

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WELDING RESEARCH COUNCIL

of the Engineering Foundation

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Supplement to The Welding Journal, February, 1950

The Work of the Ship Structure Committee

Introductory remarks by Rear Admiral Ellis Reed-Hill, Chairman, Ship Structure Committee, to open the Symposium on Ship Structure Research, Annual Meeting of the American Welding Society, Tuesday, Oct. 18, 1949, Cleveland, Ohio

MR. CHAIRMAN, members and guests of the AMERICAN WELDING SOCIETY. This morning I have been given the privilege of opening the Third Symposium on Ship Structure Research as a part of the technical session of the Annual Meeting of the AMERICAN WELDING SOCIETY. This is my third appearance in this capacity. It is extremely gratifying to me and to the Ship Structure Committee that these sessions have been so well received and are continuing on an annual basis. Each year at this time, the Ship Structure Committee, with the cooperation of the AMERICAN WELDING SOCIETY, has endeavored to present for your information a group of technical papers of current importance and interest on subjects which are being investigated by our Committee. The authors are outstanding engineers and scientists, most of whom have been associated with the Ship Structure Committee for some years and who have conducted investigations for the Committee in the solution of the ship fracture problem.

The papers being presented today are equal to, if they do not surpass, the standard which has been established during previous sessions. This year, however, there is one paper being presented, which warrants special mention. I refer to the paper entitled "Correlation of Test Results" being presented this morning by Dr. C. F. Tipper, of the University of Cambridge, in England. Mrs. Tipper is an international authority on the subject of "Brittle Fracture of Steel," and her work in this field is voluminous. She has maintained close liaison with similar work being conducted in this country, but this is the first occasion since the war on which she has had the opportunity to personally present her work before an American audience. The Ship Structure Committee is deeply indebted to the AMERICAN WELDING SOCIETY, the British Joint Services Mission and the Naval Research Laboratory for their efforts in making it possible for Dr. Tipper to be with us today.

The Ship Structure Committee represents a joint cooperative effort of five agencies—the Army, Navy, Coast Guard, Maritime Commission and American Bureau of Shipping—to promote stronger and safer welded steel ships through research in design, materials and welding methods. Assisted by cooperation with the Welding Research Council, the National Academy of Sciences, the National Bureau of Standards, the American Iron and Steel Institute and the British Admiralty Ship Welding Committee, it has been possible to reduce the number of fractures occurring annually in welded ships to one-tenth of the number originally experienced; to make progress in the introduction of a ship building steel that is more resistant to the type of fractures experienced than that formerly in use; and to accomplish refinements in detail ship design which lessen the susceptibility of welded ships to fracture.

Although the incidence of welded ship fractures has been significantly reduced, the fracture problem has not yet been completely solved. Occasional serious casualties are still taking place. You may remember the Argentine T-1 Tanker, *Capitan*, which broke in two off Cape Hatteras in December 1948. Serious shell and deck fractures continue to occur in various types of welded ships during the winter months. There is a

(Continued on page 73-s)

Correlation of Test Results

The various types of tests to determine transition temperatures are evaluated and correlated with the normal tensile test and consideration given to correlation with service experience

by Dr. C. F. Tipper

INTRODUCTION

THE many investigations which have been carried out during the past few years on problems connected with the fracture of mild-steel welded structures have revived interest in both notch sensitivity and the development of suitable mechanical tests which can assess this property. It was not at first realized that such extensive fractures, many of which occurred under conditions of static loading, were in fact identical with those obtained in small scale notch impact tests. Moreover, one of the most disconcerting results of these enquiries has been that the material which has fractured in service has given evidence of satisfactory tenacity and ductility according to existing specifications in a normal tensile test.

It is now generally recognized that loss of tenacity and ductility, which together result in some circumstances in very considerable reduction in energy absorbed to fracture, are all due to the same cause and are covered by the term "notch sensitivity" and any of them might form the basis for assessing this quality according to the test adopted for its measurement. Unless plastic deformation is curtailed by the premature cracking of a certain number of crystal grains, i.e., by the introduction of an entirely different mechanism of failure, no essential variation in mechanical properties with variation in method of testing is to be expected.

No method has been devised for determining the actual stress required to initiate fracture. The load at fracture in tension can be found experimentally in tests on single crystals when the mechanism of fracture is either by cleavage or shear, and the stress computed accordingly. In a poly-crystalline aggregate, the mean stress at which a fibrous fracture propagates has been found to equal the ultimate breaking stress of the material. When fracture is by cleavage, certain crystals break before others at a load which may be as low as the yield in uniaxial tension at the same temperature, and the nominal stress may be even lower. As soon as some crystals break, their neighbors become overloaded and, because they are simultaneously relieved of transverse restraint, can extend and fracture in a normal manner. It is clear, however, that as soon as this process begins, the unbroken crystals are unable to carry a load sufficient to cause extension in the main body of the metal to which they are attached and deformation is entirely restricted to a small zone bordering the fracture. This zone consists of crystals which have fractured after little or no plastic deformation and others which have extended to the full amount determined in a normal tensile test.

Tenacity, ductility and consequently energy absorbed must depend upon the number of crystals which break and on the stage in the deformation at which the process begins. The conditions which govern the onset of cleavage breakdown, apart from those which are essentially material dependent, are stress and temperature. The effect of time may be regarded as a subdivision of both stress and temperature.

These remarks summarize the conclusions which have been reached as a result of experimental work carried out in the Engineering Dept., Cambridge University, under the direction of Prof. J. F. Baker, O.B.E., Sc.D., and submitted in Reports (FE4) to the Admiralty Ship Welding Committee, some of which have now been published.[12]

There is general agreement between these observations and those of other investigators in this field.

The rest of this paper deals with other aspects of the problem of brittleness upon which agreement has not been reached. These may be summed up as follows.

1. Correlation between the properties measured in the normal tensile test and results obtained in notch tests of different shape and size.
2. The criterion to be adopted for assessing notch brittleness.

Dr. C. F. Tipper is with the Engineering Dept., Cambridge University, Cambridge, England.

Presented at the Thirtieth Annual Meeting, A.W.S. Cleveland, Ohio, week of Oct. 17, 1949.

* The subject matter of this paper has been submitted to the Admiralty Ship Welding Committee in the form of several reports, but the views expressed are not necessarily endorsed by the Committee.

3. How far laboratory tests can be used to predict the behavior of the metal in service.

1. CORRELATION OF TEST RESULTS

Since for a given form of testpiece and method of testing, the biggest changes occur with change in temperature, it has been customary to determine the temperature range over which the properties change and refer to it as the "transition temperature." If, however, different criteria are adopted with different methods of testing, size and form of testpieces, the transition temperatures so determined may show a considerable variation. Attention has been drawn to the unsatisfactory state of affairs which has followed the choice of different criteria in a paper by Stout and McGeady.[11] They consider choice of criterion to be more critical than choice of specimen or method of testing and when they compare the results of several investigations on the same basis, i.e., on the appearance of fracture, many of the apparent discrepancies disappear. This is logical for two reasons: (1) because the same criterion is adopted; (2) because all the properties are dependent on the proportion of crystals breaking with a cleavage fracture.

Before discussing the choice of a criterion further, a series of tests will be described which were made for the purpose of investigating the relation between the qualities measured in the normal tensile test and those in certain notch tests. Many attempts have been made to relate the properties of tenacity and ductility with the energy absorbed in notch impact tests. Confirmation that the work done in both tests is the same while the metal deforms plastically has been obtained by MacGregor and Fisher[9] among others. What is most required, however, is some clue from the tensile test to the notch sensitivity of the steel.

1.1. Experimental Results

The conventional method of measuring tenacity and ductility is by means of the tensile test; that of notch sensitiveness by the energy absorbed in an impact test. Table 1 gives the analyses of a number of mild steels of ship plate quality or removed from fractured plating and one of high manganese content, which have been subjected to a series of tests for the purpose of comparing these properties and, if possible, to find some correlation between the normal tensile properties and the temperature transition ranges of the same steels. The test results are in Table 2. Some of the results are on single specimens; others represent the mean of several. The shapes and dimensions of the testpieces used for the tensile and bend tests are set out in Fig. 1. Standard Izod and Charpy testpieces 10 mm. square in section were used for these tests.

The following observations on the various tests and procedures are necessary to assist interpretation of the results.

Table 1—Analyses of Steels, Composition Per Cent

Ref. No. →	*Z*	*H.4*	*H.V.*	*V.2**	*B.E.*	*T.5.*	*E.1**	*A.1**	*T.3**	*X.*	*H.2.*	*B.A.*	*MVT.1*	*E.K.*	*J.10*	*J.11*	*4.SAF*	*4.PFF*
Carbon	0.13	0.09	0.08	0.20	0.25	0.12	0.15	0.19	0.18	0.22	0.23	0.095	0.24	0.23	0.18	0.18	0.18	0.18
Silicon	Trace	0.5	0.07	0.04	0.11	0.02	0.07	0.052	0.03	0.04	0.02	0.07	<0.03	<0.03	<0.03	0.02	0.02	0.02
Manganese	0.45	0.32	0.23	0.57	0.54	0.48	1.07	0.57	0.60	0.37	0.37	0.50	0.39	0.43	0.40	0.53	0.35	0.37
Phosphorus	0.061	0.058	0.036	0.009	0.034	0.019	0.033	0.019	0.017	0.016	0.051	0.035	0.066	0.018	0.025	0.012	0.021	0.02
Sulphur	0.038	0.043	0.029	0.032	0.041	0.044	0.155	0.031	0.025	0.023	0.052	0.035	0.033	0.033	0.027	0.020	0.037	0.024
Nickel	0.04	0.06	0.05	0.095	0.14	0.14	0.14	0.225	0.23	0.20	0.05	0.11	0.04	0.06	0.03	0.03	0.07	0.07
Chromium	0.02	0.15	<0.02	0.03	0.05	<0.03	0.065	0.22	0.04	0.07	0.02	0.03	<0.03	<0.03	<0.02	<0.02	<0.02	0.02
Molybdenum	0.04	<0.02	<0.02	0.009	<0.02	<0.03	0.045	0.068	0.04	0.03	<0.02	0.04	<0.03	<0.03	<0.02	<0.02	<0.03	0.02
Vanadium	...	<0.01	<0.02	...	<0.02	<0.02	...	...	...	...	<0.01	...	<0.01	<0.01	<0.02	<0.02	<0.03	0.02
Tungsten	...	...	<0.02	...	<0.02	<0.02	...	...	...	...	...	...	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Copper	0.065	0.04	0.03	0.11	0.14	0.12	0.18	0.23	0.08	0.19	0.10	0.115	0.08	0.01	0.09	0.02	0.15	0.16
Aluminum	...	0.05	0.006	0.009	0.033	0.005	...	...	0.028	...	0.001	...	0.006	0.004	0.002	0.002	0.002	0.002
Nitrogen	0.024	0.012	0.015	0.004	0.006	0.007	0.004	0.004	0.005	0.006	0.006	0.004	0.012	0.017	0.009	0.012	0.009	0.006
Mn/C	3.56	3.55	2.88	2.85	2.16	4.0	7.15	3.00	3.33	1.68	1.61	5.26	1.62	1.86	2.22	2.95	1.94	2.05

* V.2, 3, 4, E.1, 2, 3, A.1, 2, 3, T.2, 3, 4—these were plates of three thicknesses rolled from same ingot. Check analyses from each plate showed only small variations from figures given above.

Table 2

Ref. No.*	Thickness, in.	Yield stress,† tons per sq. in.	Ult. stress, tons per sq. in.	Per Cent elongation on 1 in.	Reduction in area %	Ext. to max. load, %	Hounsfield slow bend‡ Total energy ft.-lb.	Hounsfield slow bend‡ Energy to max. load	Hounsfield slow bend‡ Energy to max. total %	Hounsfield slow bend‡ Fracture	Hounsfield impact‡ Ft.-lb.	Hounsfield impact‡ Fracture	Transition temperature, °C. Izod or Charpy§	Transition temperature, °C. Notch tensile‖
Z.L.	0.375	17.7	28.9	28	62	14.9	11.6	8.8	75	C	2.7	C	+50–+70	27
Z.N.L.	0.375	17.7	29.3	...	...	...	18.3	13.9	75	C	10.8	C	...	...
H.4.L.	0.37	19.05	27.45	38	70	22.1	39	18.5	47	F	39.4	F	...	–10
H.V.L.	0.45	17.5	23.3	36	65	18.1	28.8	11.5	40	F	4.1	C	+20–+30	–10
H.V.X.	0.45	18.0	24.7	29	61	16.5	14.4	6.3	43	F	4.1	C	...	...
H.V.N.L.	0.45	...	...	...	...	...	33.4	18.5	55	F	29.6	F	...	...
H.V.N.X.	0.45	...	...	...	...	...	16.7	10.9	65	F	17.0	30% C	...	...
V.2.L.	0.49	13.5	27.1	36	64	17.4	17.1	7.0	40	F	11.0	70% C	–40–+50	–7 –+7
B.E.	0.497	20.9	33.4	30	60	18.1	16.0	...	...	F	16.0	30% C	–23–+20	–14–+17
T.5.L.	0.51	14.7	25.0	37	69	20.9	25.2	15.0	59	F	23.5	20% C	–20–+20	–25–+16
T.5.X.	0.51	14.05	24.65	33	59	21.7	10.0	5	50	F	10.0	40% C	–20–+20	–28––6
T.5.A.L.	0.51	12.3	23.3	41	67	20.9	25.0	16.8	67	F	8.5	80% C	–20–+50	0–+7
T.5.A.X.	0.51	12.5	22.9	37	62	21.9	11.6	5.1	43	F specks C	8.5	75% C	–20–+50	–23–+70
E.1.L.	0.50	16.3	29.4	37	70	17.2	29.4	13.1	44	F patch C	23.0	50% C	–35– 0	–35–+2
A.1.L.	0.51	18.25	30.6	32	62	15.6	23.2	11.1	47	F patch C	18.0	75% C	–10–+10	–18–+2
T.2.L.	0.51	17.4	28.0	42	63	19.3	22.1	8.5	38	F	23.0	F	–40––16	–40––22
X.L.	0.53	19.6	31.1	34	57	16.0	16.6	7.4	44	F	7.5	90% C	0–+40	+10
X.X.	0.53	17.05	29.8	33	55	17.4	14.6	7.4	50	F	9.5	80% C	...	+6 –+18
H.2.L.	0.535	16.4	30.2	32	57	16.2	12.1	6.4	53	50% C	5.0	C	...	+8 –+40
B.A.L.	0.65	20.2	27.9	34	64	17.2	10.5	4.8	41	F	13.4	F	–10–+20	–35––12
MVT.1L	0.68	17.3	31.2	35	57	17.5	12.05	9.8	81	C	4.1	C	...	...
MVT.1X	0.68	17.5	32.6	30	50	16.3	8.35	3.9	46	C	4.0	C	...	...
MVT.2.L	0.68	20.0	34.9	30	53	17.8	4.6	4.6	100	C	10.5	C	...	...
MVT.2.X	0.68	20.0	27.0	20	42	13.0	3.7	3.7	100	C	2.5	C	...	...
V.3.L.	0.72	12.5	26.3	36	62	19.8	22.0	7.4	33	F	19.0	50% C	–30–+40	+5–+43
T.3.L.	0.735	15.0	28.2	37	66	18.6	24.9	11.6	46	F	23.5	20% C	–30–+40	–2 –+35
E.K.L.	0.735	14.2	29.0	30	57	17.5	16.8	7.6	45	F	8.9	90% C	–10–+30	...
E.K.X.	0.735	14.2	28.4	33	52	19.2	11.3	4.8	42	F	9.5	80% C	...	...
A.2.L.	0.74	16.7	30.3	36	63	17.3	19.5	8.8	45	F patch C	16.0	80% C	0–+60	+24–+56
J.10.L	0.91	16.0	33.4	26	45	16.0	12.2	8.1	66	80% C	5.5	C	+20–+60	...
J.10.X	0.91	14.7	29.4	30	58	16.3	10.9	5.5	50	80% C	5.0	C	+20–+60	...
J.11.L	0.91	14.5	26.3	37	61	20.3	18.7	11.1	59	F	14.0	75% C	–10–+30	...
J.11.X	0.91	15.4	26.0	30	55	17.2	12.9	5.5	42	F	6.5	90% C	–10–+30	...
V.4.L.	0.96	13.0	27.7	34	60	18.1	15.5	9.25	59	C	19.0	60% C	0–+70	+30–+90
A.3.L.	0.97	19.5	37.2	24	50	13.2	6.5	4.25	65	C	5.5	90% C	+10–+80	+40–+80
T.4.L.	0.985	16.0	28.9	37	64	18.4	31.0	10.2	33	F patch C	25.5	30% C	–40–+60	+3 –+58
T.6.A.L.	0.99	12.4	22.6	43	67	21.3	31.5	20.3	64	F	9.3	90% C	–10–+50	+2 –+46
T.6.A.X.	0.99	12.6	22.7	38	49	21.0	12.2	6.85	56	F	6.5	C	0–+56	0–+56
E.3.L.	1.00	16.25	30.2	34	67	15.9	22.0	12.0	54	F	20.0	60% C	–30–+30	–10–+80
4.SAF.L	1.23	13.6	28.7	30	40	18.1	14.6	10.0	68	90% C	5.0	C	0– 60	...
4.SAF.X	1.23	12.6	27.2	32	45	18.8	11.1	7.6	68	90% C	5.5	C flaw	0– 60	...
4.PFF.L	1.28	14.7	28.2	34	54	18.2	18.0	6.45	35	60% C	6.0	90% C flaw	6– 60	...
4.PFF.X	1.28	13.7	28.4	22	35	16.7	12.7	5.55	43	50% C	5.0	C	0– 60	...

* L = Testpiece cut in direction of rolling; X = testpiece cut across direction of rolling; N = normalized; A = annealed.
† Lower yield stress.
‡ Temperatures of tests—13–19° C., 55–65° F.
§ From temperature–energy curves, commencement to end of fall—10 mm. sq. Izod, notch-in-plate section.
‖ From appearance of fracture, completely fibrous to completely crystalline—1 in. wide, 2 Izod notches, 1/8 in. deep, full plate thickness, notches in plate section.

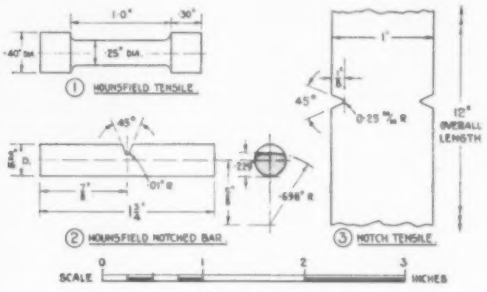

Figure 1

1.2. Tensile Tests

There are drawbacks to using small testpieces, particularly when they must be cut from bars or plate of large dimensions, in that they may not be truly representative of the whole sample, e.g., if a testpiece is cut from the center of a 1-in. plate which has a considerable rim. Except in heat-treated or rimming steels, agreement between large and small testpieces has been found to be remarkably consistent. In the present investigation all tensile tests were made on the same dimensioned specimens so that the results are strictly comparable.

In the small machine used for these tests, the specimen is fixed to the centre point of a flat spring, and load and extension are plotted by hand on a rotating drum. A typical record is shown in Fig. 2. It is necessary to subtract the spring deflection from the total extension on the record to obtain that of the specimen. The magnitude of the additional extension due to the spring can be judged from the inclined line to the left of the diagram. The force scale is unaffected.

The extension to maximum load was made from the records; total extension was measured on the specimen after fracture. The former was measured to the point at which the load started to fall and may be said to represent the uniform plastic extension up to the point of neck formation. It is recognized that discrepancies may arise due to incorrect determination of this point, but the errors are slight.

Reduction in area measurements were made in the usual way. In plates which were laminated and showed considerable directional properties, the mean value has been given.

1.3. Bend Tests

The objection to using small specimens applies to a greater extent in notch tests. The purpose of these experiments, however, was to make both slow bend and impact tests on identically shaped testpieces with three-point loading. In the first, load deflection curves were plotted in the machine used for the tensile tests. In the second, the Hounsfield Balanced Impact machine was used which is of the Charpy type. Both arms, one of which carries the specimen, are released simultaneously. The energy is 48 ft.-lb. and the striking velocity 22.7 ft. per second.

The testpieces are round and care was taken to mark the ends so that the notch could always be cut in a direction perpendicular to the plane of the plate in order that these tests could be compared with the Izod or Charpy and notch tensile tests.

Both slow bend and impact tests were carried out at room temperature, i.e., between 13 and 19° C, 55–66° F. It is not considered that variations of this magnitude could affect the results seriously.

The character of the fractures was noted and the crystalline areas estimated.

The areas under the slow-bend curves were measured and the total energy to fracture calculated and compared with the energy to fracture in impact.

The area of the curve up to maximum load was also measured. This load was considered to represent approximately the point at which fracture at the base of the notch began to propagate. From this point onward the load fell slowly or steeply according to the nature of the fracture. The percentage of energy absorbed to maximum load to the total energy absorbed is a measure of the brittleness of the fracture. If it is high, the fracture is brittle. These figures are given in Column 10 in Table 2. Typical curves are illustrated in Figs. 3, 4 and 5.

1.4. Izod or Charpy and Notch Tensile Tests

The transition temperature was determined for a number of plates by either Izod or Charpy with Izod notch, or notch tensile, or by both methods.

It has been found that, with few exceptions, the transition range based on fracture appearance in notch tensile tests falls within the drop in the energy vs. temperature curves obtained by means of Izod or Charpy tests, and is quite sharply defined. It has also been found that the temperature range determined using Hounsfield specimens and testing machine is very close to that of the standard testpieces although the energy values differ. A correction can be applied to bring the two values in line, but for the present purpose, this is unnecessary.

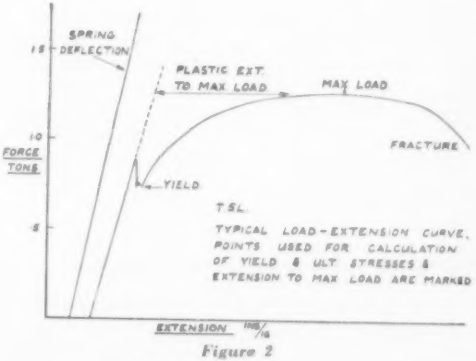

Figure 2

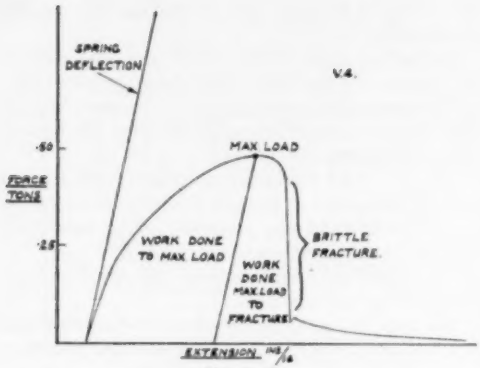

Figure 3

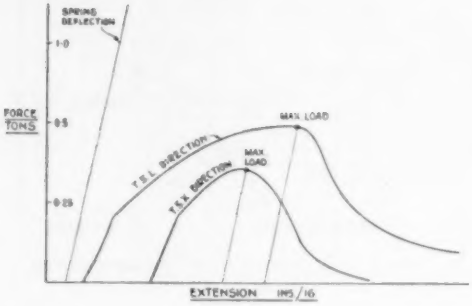

Figure 4

2. DISCUSSION OF RESULTS

From what has already been said in the introduction to this paper, some relation between tensile-test results and notch-bend and notch-tensile results is to be expected whenever plastic deformation occurs. Agreement is closest when the fracture is fibrous.

It is possible to divide the properties into two groups; one, which affects the values such as extension and maximum load and hence energy absorption, and the other group which becomes most important as soon as fracture begins. A somewhat similar separation into groups has been made by Stout and McGeady.[10,11] Division is not clear-cut and there is considerable overlapping.

In the first group must be placed the yield stress and yield-point strain, the work-hardening properties, including tendency to strain age hardening and the metallurgical structure including the presence and character of the nonmetallic inclusions.

As soon as fracture begins, if it is chiefly by shear, there is no break in continuity and, except that inclusions facilitate breakdown by dividing the testpiece into plates or fibers,[3, 12] no new factor is introduced.

If, however, fracture is largely by cleavage, the properties of the metal associated chiefly with plastic flow are unable to exert their full influence. Instead of energy being absorbed, there may even be a release of elastic strain energy. The metallurgical structure, grain size, size and distribution of nonmetallic inclusions, however, continue to be important factors in facilitating or hindering crack formation and propagation.

Bearing these facts in mind, it is now possible to compare the properties as far as they can be determined quantitatively, by the various tests to which the steels have been subjected.

2.1. *Yield Stress and Yield-Point Strain*

A low yield stress may merely indicate a steel with low-carbon and other elements content, or it may be due to a large number of inclusions. If due to the former, a low yield may be desirable in facilitating early stress relief at the bottom of a notch. This would depend upon whether the low yield were followed by a steeply rising load/extension curve, indicating a tendency to rapid strain age hardening. A long yield is to be desired for the same reason and fine grain size which is associated with a high yield strain has been found to promote resistance to notch brittleness.

Looking down the figures in Column 3 of Table 2 however, the yield-stress values give no clue to notch sensitivity. This is immediately apparent from the fact that the difference in yield stress in the two directions of rolling is negligible, while there is a large difference in notch tests made in the two directions.

2.2. *Ultimate Tensile Strength*

The ultimate tensile strength might be expected to affect the energy absorbed, but, here again, no great difference in its value is obtained when specimens are cut in the two directions of rolling, and some steels having a low ultimate show high energy absorption in notch tests.

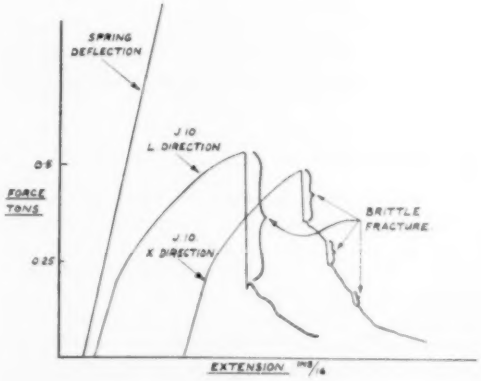

Figure 5

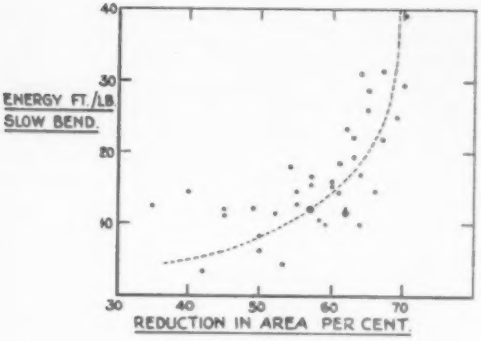

Figure 6

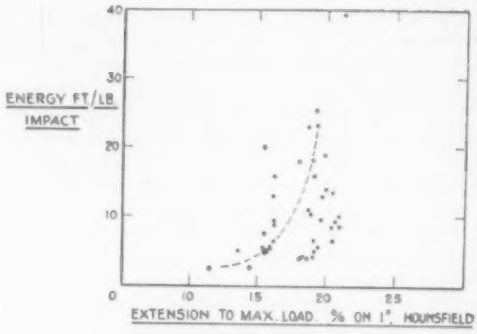

Figure 8

2.3. Elongation and Reduction in Area

The measurement of these values gives an indication of ductility. Elongation can be divided into uniform extension, the figures for which are given in Table 2 and that associated with necking, normally measured by percentage reduction in area.

Comparing the figures listed in Table 2, there appears to be a connection between total elongation and reduction in area in tensile tests and energy absorbed and type of fracture in notch bend tests. Marked differences are sometimes recorded in reduction in area figures when the testpieces are cut in the two directions of rolling and to a lesser extent the same tendency is shown in elongation measurements. It is clear, however, that what differences appear in the elongation figures must be attributed chiefly to the extension during necking, rather than to the uniform extension. In view of their importance the figures for energy absorption against reduction in area and energy in impact vs. uniform extension have been plotted in Figs. 6, 7 and 8. The conclusion may be drawn that good ductility ensures plastic strain at a notch and hence stress relief and high reduction in area figures indicate resistance to fracture.

2.4. Notch Bend, Slow and Impact

There is some difference in most steels between energy absorbed in notch tests according to the position of the notch in relation to the direction of rolling. The highest energy figures are obtained when the notch is in the plane of the plate. No tests with the notch in such a position are included in this list, but the differences due to direction of rolling with the notch perpendicular to the plate surface are still large in both slow bend and impact.

There is a marked tendency for the energy values in impact to be lower than those in slow bend and the decrease is associated with an increase in crystallinity of fracture. The points are plotted in Fig. 9 and only a few lie below the dotted line which represents equality in slow bend and impact. A certain scatter in results is unavoidable in these tests, but there is no doubt about the trend.

The energy absorbed to maximum load includes that due to the uniform bending of the bars between the supports as well as to that due to local deformation at and behind the notch. As soon as a crack has formed, which is considered to be near the point of maximum load, deformation is largely confined to the region of the notch.

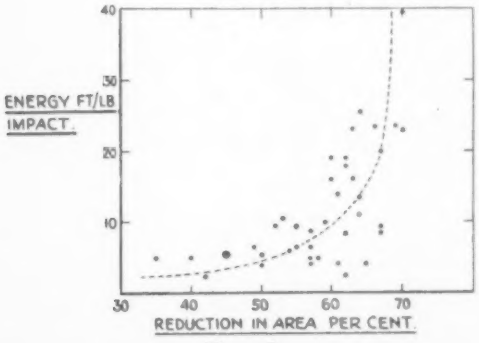

Figure 7

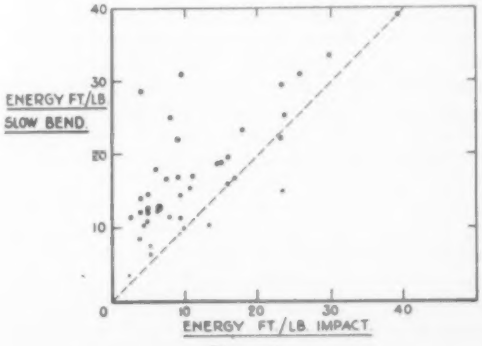

Figure 9

Plastic deformation is time dependent and Holloman[6] has suggested that increasing the strain rate is equivalent to lowering the temperature in the effect on fracture. Reference to Table 2 shows that in the few cases where the fracture was fibrous in impact, the energy absorbed was slightly higher than in the slow tests as might be expected. The temperature of testing most of the steels was within the transition range determined by means of impact tests (see last column but one in Table 2) and in these steels the effect of impact is to raise the transition range by increasing the crystalline areas for the same temperature.

The explanation of the time effect in these tests may be attributed to the stress relief afforded by plastic flow in lowering the stress concentration at the notch, or at internal notches, which cannot take place if the peak load is reached too rapidly, but at the present time there is insufficient data upon which to base any definite conclusions. There is also no explanation of why some steels are sensitive to impact and others are not, although some tentative suggestions are discussed in Section 3.

3. TRANSITION TEMPERATURES

Since there appears to be a relationship between elongation, reduction in area figures and amount of cleavage fracture in notch bar tests, it might be expected that the values for these two properties would decrease as the temperature falls. This is generally found to be so, although the change in elongation and reduction in area which occurs over the transition temperature range in notched bars is slight.

The following table gives some results of normal tensile tests at room temperature and lower. The dimensions of the testpieces used were as given in Fig. 1.

Plate	*Temp., °C., yield*	*Yield stress, tons per sq. in.*	*Temp., °C., max.*	*Ultimate tensile strength tons per sq. in.*	*Per Cent elongation on 1 in.*	*Reduction in area, %*
H.1	9	16.65	9	27.8	35	70
	−55	19.35	−55	30.3	42	61
	−78	20.85	−65	31.2	40	61
H.2	10	16.4	10	30.2	32	69
	−39	17.85	−38	32.3	32	57
H.4	10	19.05	10	27.45	38	70
	−47	20.03	−46	29.4	37	69

Whereas yield and ultimate stresses rise with fall in temperature, elongation is only slightly affected. There is some evidence of decrease in reduction in area figures for plates H.1 and H.2. The transition temperature for H.2 is high; that for H.4 is low (see Table 2). No figures for H.1 are available. The reduction in area figures may aid in indicating a tendency toward notch sensitivity, but it does not seem as if they could be used to fix the transition temperature.

It has been found that the transition temperatures of steels, however measured, place them in the same order with respect to one another.[2] Comparing Izod or Charpy (impact) results with notch tensile (static), approximately 75% of the steels tested* by both methods undergo a change in fracture in notch tensile tests over a shorter temperature range than in impact tests, but at the same time well within that range. Of the others, nearly all have a lower transition temperature in the static test. This fact links up with the observation in the previous section on the relation between slow and impact bend tests.

The steels which show this anomaly are nearly all those of very low-carbon content, or have been slowly cooled, as for example H.V., T.5.A. and T.6.A. In such steels there is a tendency for the carbon to segregate in the crystal boundaries while the ferrite is coarse grained and very soft. Although fractures have not been observed to follow crystal boundaries, the presence of a brittle, intercrystalline substance may still facilitate the passage of cleavage cracks from one grain to another. On the other hand, the low yield stress would enable yielding to occur at the notch bottom in static tests.

Here is an example in which different results obtained by different methods of testing are related to the inherent properties of the steel and in such a case uniformity in test results could never be achieved.

4. DIMENSIONS

The dimensional effect in testing has received considerable attention.[2, 4, 7, 8, 13] Many results are vitiated because differences in metallurgical structure become involved. A full discussion of the problem is outside the scope of this paper which describes the results on uniformly small specimens, with the exception of the notch tensile tests which were carried out on the full plate thickness.

The effect of dimensions becomes most pronounced in those tests such as the "Tear Test"[6] and that of Bagsar,[1] which are subject to eccentricity in loading. The transition temperature varies, because of structural as well as stress differences. Since the criterion has also varied with the change in specimen form and size used in the different investigations, it is almost impossible to compare the test results.

Increasing plate width does not introduce a new factor such as increasing thickness and the greatest effect is produced in geometrically similar testpieces in widths up to 6 in. It can be shown that however fracture is initiated and whatever the original shape of notch, a natural fracture front is eventually formed which only appears to depend upon the material, thickness of plate and temperature of test. If the testpiece size is such that the natural notch cannot form before fracture is complete, all the values measured in notch tests will vary with testpiece dimensions. Beyond this size, increases in width of plate tested are likely to have less effect and there appears to be no point in increasing the dimensions

*Altogether 45 plates have now been fully investigated by both methods.

further. The transition temperature determined by 1-in. wide notch tensile tests has made it possible to predict the temperature of change in fracture in tensile testpieces up to 14 in. wide.

The use of small notched testpieces should therefore be confined to such problems as comparing the relative merits of various steels. Full thickness and adequate width are required to gage the behavior of the material with respect to the full-scale structure.

GENERAL SUMMARY AND CONCLUSIONS

1. Some clue to the tendency to notch brittleness in structural mild steel can be obtained from the ductility, particularly reduction in area, exhibited in the normal tensile test.

2. The transition temperatures cannot be predicted from the tensile test results, although low transition temperatures are associated with high values of reduction in area.

3. The energy absorbed in notch bend tests appears to depend more on the ductility of the steel than upon its strength.

4. The energy absorbed in slow bend tests is greater in a large number of steels than it is in impact. A similar effect in some instances is observed on comparing the transition temperature of Izod and Charpy tests and notch tensile tests. Thus, the transition range appears to be displaced to higher temperatures by increased rates of loading.

5. For the same steel, decrease in energy absorbed is accompanied by an increase in crystallinity of fracture.

6. At the present time, the appearance of fracture is the logical criterion of brittleness to adopt. It is recognized that such a criterion is only qualitative. It is, however, the common factor which influences all the mechanical properties and gives the most consistent figures for the determination of transition temperatures. If any other criterion is adopted, it would appear to be necessary to specify form of testpiece and method of loading.

7. To obtain any correlation between laboratory tests and service failures it is advisable to use testpieces having the full plate thickness and the width to be sufficient to permit development of the natural fracture.

ACKNOWLEDGMENT

I wish to express my thanks to the Committee for their encouragement and support throughout these investigations and to Prof. J. F. Baker, O.B.E., Sc.D., Head of the Engineering Dept., Cambridge University, where this work has been carried out.

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Discussion by W. S. Pellini and C. E. Hartbower

Dr. Tipper concludes regarding the determination of transition temperatures that "At the present time, the appearance of fracture is the logical criterion of brittleness to adopt—" and that "If any other criterion is adopted, it would appear to be necessary to specify form of testpiece and method of loading." These deductions have a far-reaching significance, in that it is implied that the form factor (mechanics of specimen) may thus be eliminated from consideration by use of the brittleness criterion. This of course is the long sought for goal of correlation—the evaluation of an "inherent" transition property devoid of complications engendered by specimen effects *per se*. Such an important conclusion should bear searching and rigorous analysis.

There is no question that a consideration of fracture appearance represents a sound basis for the evaluation of material performance in the presence of a natural crack. For that matter any criterion which evaluates the work done in the propagation of a natural crack front serves equally well, for example, postcracking energy absorption is known to bear a rigorous relationship to fracture appearance. Energy criteria, however, lack the simplicity and directness of fracture examination criteria. Moreover, a brittle fracture presents incontrovertible evidence of low-energy propagation of a crack and is therefore sufficiently definitive in itself.

In order to evaluate the progression of a natural crack in terms of fracture appearance, the design of specimen must be such that the crack travel for a

W. S. Pellini is Head, and **C. E. Hartbower** is Metallurgist, Metal Processing Branch, Metallurgy Div., Naval Research Laboratory.

sufficient distance to develop crack front conditions which are determined by the inherent properties of the steel. Dr. Tipper evidently agrees with this philosophy in that she states "It can be shown that however fracture is initiated and whatever the original shape of the notch, a natural fracture front is eventually formed which only appears to depend upon the material thickness of plate and temperature of test. If the testpiece size is such that a natural notch cannot form before fracture is complete, all the values measured in notch tests will vary with testpiece dimensions." The original statement under discussion regarding appearance of fracture as the criterion of brittleness should thus be interpreted to apply only to a special class of large specimens. It should be realized that small specimens, such as the Charpy, depend so greatly on the precrack stage that correlation between specimens containing variations in the machined notch, even on a basis of fracture appearance, is not to be expected. The following résumé of project steels provides substantive evidence for this conclusion.[1]

Table 1—Transition Temperature Based on Fracture Appearance*

Slow-bend notch bar				*Edge notched tensile*	
0.0015-in. radius pressed notch		*0.01-in. radius milled notch*		*0.031-in. sawcut*	
Q	−5	H	−25	Br	−25
H	0	Br	−10	Dn	40
Br	0	Q	0	Q	80
Dn	30	Bn	35	Dr	80
Dr	60	Dn	40	H	100
A	65	Dr	50	A	105
E	95	A	55	Bn	105
Bn	100	E	85	E	105
C	130	C	125	C	140

* The highest temperature in the transition zone.

In contradistinction, investigations of Kahn and Imbembo[2] using comparatively wide tear specimens have shown relative insensitivity to the initial notch conditions. The fracture appearance was shown to remain unchanged by varying the notch from a 0.039 in. radius to a sawcut 0.010 in. wide.

All of this is, of course, merely background for the all-important question regarding the correlation between laboratory specimens and monolithic structures. Dr. Tipper concludes that "To obtain any correlation between laboratory tests and service failures it is advisable to use testpieces having the full plate thickness and the width to be sufficient to permit the development of the natural fracture." The word "any" is most important in the interpretation of this statement. If it should be considered to imply "some" or a "degree" of correlation, we would agree with the statement inasmuch as we are strongly of the opinion that a rigorous correlation between the performance of simple laboratory specimens and full-scale structures is untenable. Our opinion is based on the general recognition of the fact that the performance of a structure (or any specimen) depends on the combined effects of mechanical and material factors. Mechanical factors include the imposed conditions of service and design which determine the state of stress, rate of straining, temperature, etc. Material factors include the numerous and sometimes elusive elements which characterize steel quality; viz., notch and strain rate sensitivity, strain aging susceptibility, structural homogenity, etc. The complexity of this interplay of factors is such as to preclude correlation between service structures and simple laboratory specimens except in a very approximate sense subject to wide chance fluctuations requiring statistical analysis.

In order to illustrate the very real nature of these complexities, attention is called to certain results obtained at the Naval Research Laboratory. Two independent series of V-notch Charpy specimens were taken 10 ft. apart in a single as-rolled plate 24 ft. long. Marked differences in transition temperature resulted. All criteria examined were consistent in showing the difference due to position in the plate but they did not agree as to the magnitude of the difference.

Transition Temperature, ° F.

Position in plate	*Onset of brittleness*	*50% max. energy*	*15 ft.-lb. energy*
A	80	20	−20
B	200	70	20

Further evidence of the variations that can occur within a single plate was demonstrated by a comparison between transition temperatures determined in impact and slow bend using the standard V-notch Charpy bar.

Transition Temperature, ° F.

	Position A		*Position B*	
	Impact	*Slow bend*	*Impact*	*Slow bend*
50% max. energy	20	−10	70	50
Onset of brittleness	80	20	200	90

If we are to accept the fact that Charpy tests are influenced greatly by the precrack stage of fracture, the above observations can be interpreted as evidence that crack initiation tendencies may vary markedly even in a single plate depending upon anisotropy and gross segregation effects. Dr. Tipper notes similar effects. Such variations in crack initiation tendencies indicate that differences must be expected in service behavior depending on the specific section of the plate which suffers critical deformation. The evaluation of the crack initiation tendencies of a plate for correlation purposes therefore presents a sampling problem which can only be resolved by statistical methods. In practice this problem assumes inordinate complexity since service notch conditions vary over a wide spectrum. However desirable, it is not possible to avoid the statistical approach by the artifice of testing a large specimen and then seeking correlation on a basis of fracture appearance, because this criterion is relatively insensitive to the crack initiation stage in large speci-

(*Continued on page 73-s*)

Distribution of Relative Ductility in Steel Weldments

Lower ductility zones are indicated in $^3/_4$-in. ship plate from 0.3 to 0.4 from the weld center line. Preheat and postheat treatment improve ductility and lower transition temperature

by L. J. Klingler and L. J. Ebert

Abstract

An investigation was made to determine the dependence of zones of low ductility in weldments upon the steel and upon the welding conditions and heat treatment. The ductility was evaluated by means of eccentric notch-bar tension tests conducted at various low temperatures.

A zone of low ductility was found in two low-carbon ship-plate steels at a distance of 0.3–0.4 in. from the weld center line when the weldments were made on $^3/_4$-in. thick plate with 100° F. preheat and interpass temperature.

A 400° F. preheat and interpass temperature improved the ductility in the critical zone, lowering the transition temperature from −20 to −45° F.

A 1100° F. postheat practically eliminated the zone of lowered ductility, the transition temperature being lowered to −70° F.

Temperature measurements made during welding showed that the critical ductility region had not been heated above the lower critical temperature.

No change in microstructure could be noted between the critical zone and the unaffected base plate. Microhardness tests showed only slight hardening in the embrittled region.

The occurrence of the embrittled region is thought to be due to some suberitical temperature phenomena which may be the supersaturation and precipitation of carbon or carbides from the alpha phase.

INTRODUCTION

EXAMINATIONS of commercial failures have shown that steel structures may fail in a brittle manner if subjected to certain service conditions. The conditions which may lead to brittle failure include multiaxial stresses, stress concentration, low temperature, section size and rate of loading. Considerable attention has been drawn to these factors with the occurrence of failures in welded merchant ships.

The ductility of a metal or a structure loaded under a combination of these embrittling factors may be reduced to a low value. The ductility then becomes a more important measure of the structure's resistance to failure than its strength, since it is known that a crack can propagate through a region of low ductility with the absorption of only a small amount of energy.

Since the number of failures in ship structures increased with the adoption of welding techniques, it would seem that the welding procedures introduce some change in the properties of the steel plate. Various investigations employing a number of different test specimens have shown that the ductility of a weldment is lower than the ductility of the steel of which the weldment is made.

The general purpose of this investigation was to establish the existence of zones of low ductility in commercially welded ship plate by means of a test which would be sensitive to variations in material and welding conditions. If such zones could be isolated, investigation was to be made of their dependence upon material, variations in the welding process, and heat treatment.

MATERIAL

The ship plates selected for this investigation were two of the so-called "project steels" which have been investigated by other groups under the sponsorship of the Ship Structure Committee. Steel C was selected because it has been shown to have a high-transition temperature, and Steel A was chosen because it has lower transition temperature although it has the same approximate composition. Both were semikilled steel and in the as-rolled condition.

The analyses and properties reported for these steels[1] are shown in Table 1.

PROCEDURE

Test Specimen

Many types of specimens have been used to evaluate

L. J. Klingler and **L. J. Ebert** are associated with the Metals Research Laboratory, Dept. of Metallurgical Engineering, Case Institute of Technology, Cleveland, Ohio.

This paper is based upon the results of work conducted at the Metals Research Laboratory, Case Institute of Technology, under the sponsorship of the Ship Structure Committee under Bureau of Ships Contract NObs-45470. The opinions expressed in this paper are those of the authors and do not necessarily represent the opinions of the Ship Structure Committee.

Presented at the Thirtieth Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

Table 1—Properties of Steel Plate

Chemical analysis, %

	Carbon	*Manganese*	*Phosphorus*	*Sulphur*	*Silicon*
C steel	0.24	0.48	0.012	0.026	0.05
A steel	0.26	0.50	0.012	0.039	0.03

	Aluminum	*Nickel*	*Copper*	*Chromium*	*Molybdenum*
C steel	0.016	0.02	0.03	0.03	0.005
A steel	0.012	0.02	0.03	0.03	0.006

	Tin	*Nitrogen*	*Vanadium*	*Arsenic*
C steel	0.003	0.009	<0.02	<0.01
A steel	0.003	0.004	<0.02	<0.01

Mechanical properties

	Yield point, psi.	*Tensile strength, psi.*	*Elongation, %*
C steel	39,000	67,400	25.5 (8-in. gage)
A steel	37,950	59,910	33.5 (2-in. gage)

the properties of welded structures. Since the zones of low ductility were expected to be small, a specimen was needed for this investigation, which would test a small volume of metal and still include the various embrittling factors. The eccentric notch-bar tension test meets these requirements in that a very small volume of metal controls the reaction of the specimen, the embrittling factors of eccentric loading, multiaxial stress and a stress-raiser are present and the factor of low temperature can be added.

This specimen has been used in a number of investigations to differentiate among steels, heat treated to the same strength levels, which are known to have different service properties.[2,3] In Fig. 1 the properties

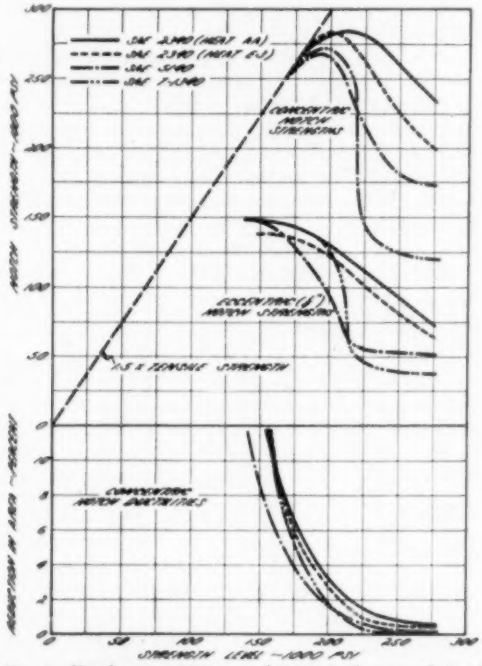


Fig. 1 Notch properties as a function of strength level for various steels[3]

of four steels are compared by means of concentric and eccentric notch tests.[2] A definite relation can be seen between eccentric notch strength and concentric notch ductility for ductilities up to 10%. In Fig. 2 the same

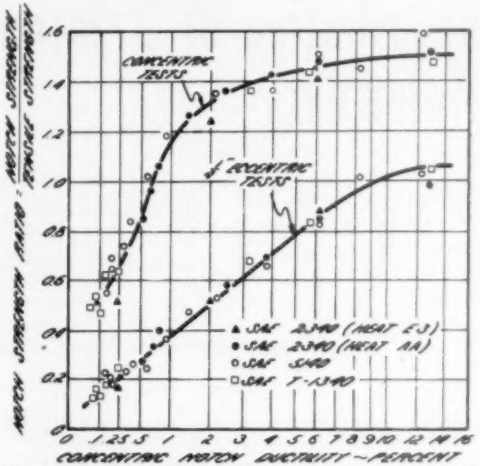


Fig. 2 Relations between concentric and eccentric notch strength ratios and notch ductility[3]

data are replotted to show the eccentric notch strength as a function of concentric notch ductility for the four steels. The eccentric notch strength, therefore, reflects the concentric notch ductility and should give an accurate indication of the regions of low ductility in a weldment.

Welding Procedure

All of the weldments were made at Battelle Memorial Institute under closely controlled conditions. Details of the welding process are given in Figs. 3 and 4.

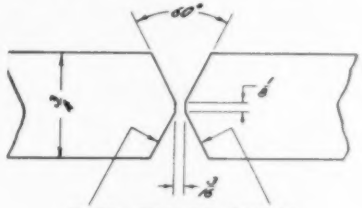


Fig. 3 Plate preparation

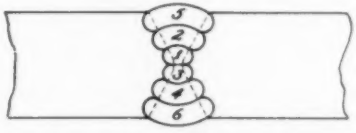


Fig. 4 Welding procedure

Each weldment was 18 x 24 x $^{3}/_{4}$ in., constructed of two plates 9 x 24 x $^{3}/_{4}$ in. in dimensions with the 24-in. dimension being in the rolling direction of the plate. These plates were flame cut from the same large plates and $^{3}/_{4}$ in. was machined from the edges to be welded in order to eliminate the heat effect of the flame cutting. The edges to be welded were then machined to a 30° bevel and $^{1}/_{8}$-in. root face as shown in Fig. 3.

The plates were tack welded using 1-in. tacks at each end and at the center of the plate, leaving $^{3}/_{16}$ in. clearance between the root faces. A copper back-up bar coated with a thin layer of wollastonite was used for the first weld pass.

No restraint other than the tack welds was used on the weldments and since 2 in. from each end of the plate were to be discarded, no runoff tabs were required. All welding was manual, using E6010, $^{3}/_{16}$-in. diameter electrodes with reverse polarity. The welding data are given in Table 2.

Table 2—Welding Data

Harnischfeger—d.-c. welder

	Electrode $^{3}/_{16}$ *E6010*	*Reversed polarity*
Current, amp.	150	Pass 1
	165	Passes 2–6
Voltage, v.	25	Passes 1–6
Welding speed, in./min.	3.6	Pass 1
	4.8	Passes 2–6
Electrode burn off rate, in./min.	8.5	Passes 1–6

The weldments were preheated to the predetermined temperature prior to the first weld pass. After each pass the weld joint was cooled normally in still air until the desired temperature was reached and then the next pass was made.

Weldments were made using 100° F. preheat and interpass temperature and 400° F. preheat and interpass temperature.

After completion of welding, the welded joint was sand blasted and then radiographed for weld imperfections.

Temperature Measurements

Tempilaq was used on some of the weldments to determine the 600 and 1300° F. isotherms on the surface.

Temperature measurements were made during welding at the center of the plate (in the thickness direction) on two weldments with 100 and 400° F. preheat and interpass temperatures, respectively.

Thermocouples were placed at varying distances from weld center line so that the range of temperature from 1300 to 600° F. could be covered. The thermocouple holes were $^{3}/_{32}$ in. diameter drilled at 30° angle, parallel to the machined bevel surface. The holes were staggered so that the temperature distribution was not disturbed in front of each thermocouple.

Photo, courtesy Battelle Memorial Inst.

Fig. 5 Setup for measuring plate temperatures during welding

Figure 5 shows one of the weldments with the thermocouples in place.

All temperature measurements were made at the center of the plate, the same region that was tested in the eccentric notch tests. High-speed recorders were used to record the temperatures from the start of each welding pass until some time after the pass was completed.

Specimen Preparation

Strips, $^{1}/_{2}$ in. wide, were cut from the welded plates perpendicular to the weld. Each strip was etched so that the weld area was visible and so that the vertical center line of the weld could be located. The specimen locations were then laid out so that the notch bottom was the desired distance from the weld center line and so that the fiber carrying the highest tension load was along the center plane of the plate. The location of such a specimen in a plate is shown in Fig. 6.

The notch-test specimen is shown in Fig. 7. These specimens had a circumferential 60° V-notch removing 50% of the cross-sectional area, and a root radius of less than 0.001 in.

Testing Procedure

The specimens were tests in fixtures designed to yield a nominal eccentricity of $^{1}/_{4}$ in. The specimens

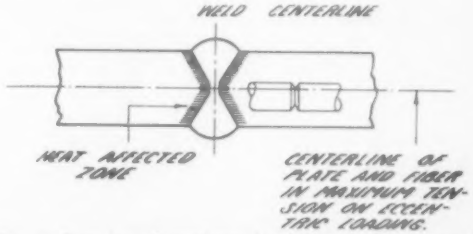


Fig. 6 Location of specimen in thickness dimension of weldment

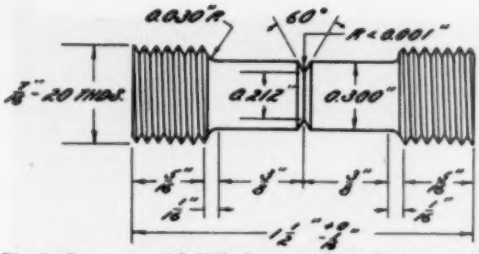


Fig. 7 Specimen with 50% sharp notch used in eccentric testing

were placed in adapters so that the fiber from the center of the plate received the maximum tension as shown in the sketch in Fig. 8. The tank for low-temperature testing is shown in Fig. 9 with the specimen in place.

The specimen was cooled to a temperature about 5° F. below the desired testing temperature, allowed to warm up to the testing temperature and then was tested. The tests were performed at constant temperature since the testing time was about 30 sec. whereas the warming-up rate was about 1° F. per minute. The specimens were cooled in an isopentane bath by means of dry ice or liquid nitrogen. Temperatures were measured by placing a pentane thermometer directly beside the specimens. All of the tests were carried out at a low strain rate.

The property that was measured was the eccentric notch strength, maximum load divided by the original cross-sectional area at the notch bottom.

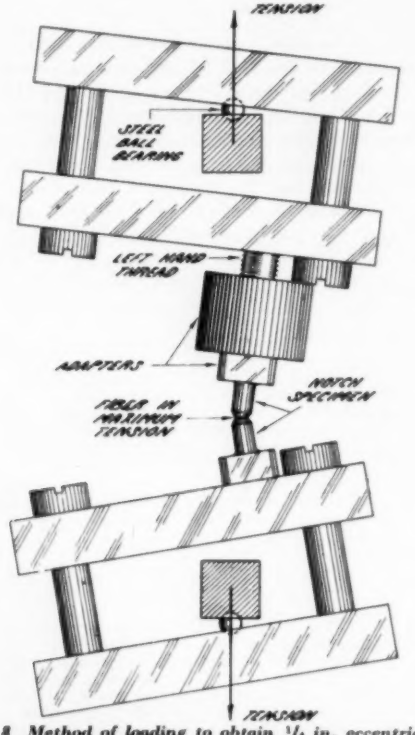


Fig. 8 Method of loading to obtain 1/4 in. eccentricity (eccentricity and the position of fixtures are exaggerated)

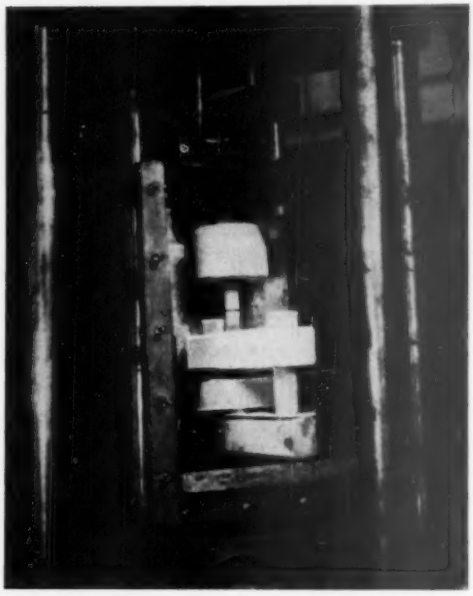


Fig. 9 Tension test fixtures for producing a controlled eccentricity of 1/4 in. with tank for low temperature

RESULTS

Steel C

The first phase of the investigation was conducted on C steel welded with 100° F. preheat and interpass temperature.*

The results of the eccentric notch tests on the unaffected base plate† are shown in Fig. 10. A ductile-brittle transition region is seen to occur between −40 to −80° F. It can also be seen that considerable variation of values occurred at the various testing temperatures. Normally, as the testing temperature of a pearlitic steel is lowered, the degree of scatter is small until the transition zone is reached. At this point, previous investigations on the effect of testing temperature indicate that considerable scatter should occur. The variation in values at the higher testing temperatures must then be attributed to inhomogeneity of the material which can be detected by the eccentric notch test.

* 100° F. was chosen rather than room temperature so that the welding conditions could be duplicated easily.

† Unaffected base plate specimens were taken at distances of 2 in. or more from the weld center line and thus were unaffected by the welding, since the maximum temperature reached in this zone was less than 600° F. for all welding conditions.

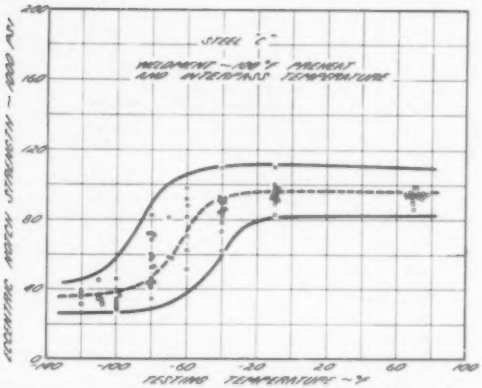


Fig. 10 Eccentric notch strength of the unaffected base plate as a function of testing temperature

The transition temperature* for the unaffected base plate is about −65° F.

In Figs. 11–15 the distributions of eccentric notch strengths across the weldment are shown for various testing temperatures as a function of test specimen position in the weldment.

The results at room temperature, Fig. 11, indicate that the eccentric notch strength was fairly uniform across the weld. However, a region of high-notch strengths indicated by the dashed lines, probably was missed. This would appear to be the case when the other distributions of notch strengths are considered.

The distributions at the lower testing temperatures all have the same general trends. The unaffected plate

* Transition temperature is here defined as the temperature at the vertical midpoint of the average notch strength curve (dashed line in the figures), which gives about the same temperature as the knee in the upper distribution limit.

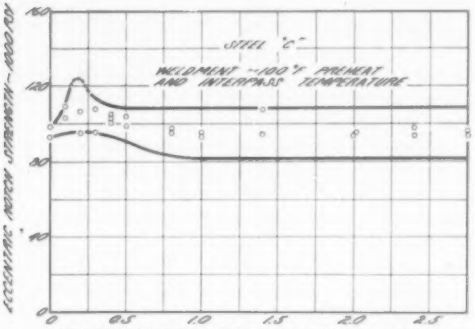


Fig. 11 Distribution of eccentric notch strength at room temperature

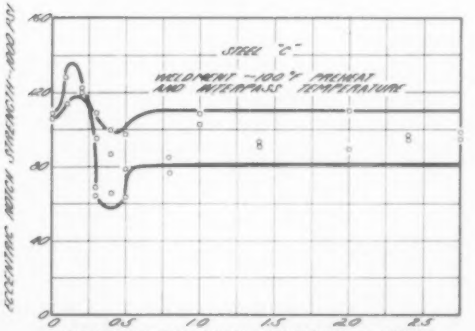


Fig. 12 Distribution of eccentric notch strength at −10° F.

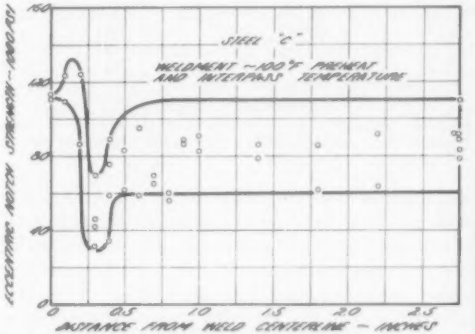


Fig. 13 Distribution of eccentric notch strength at −40° F.

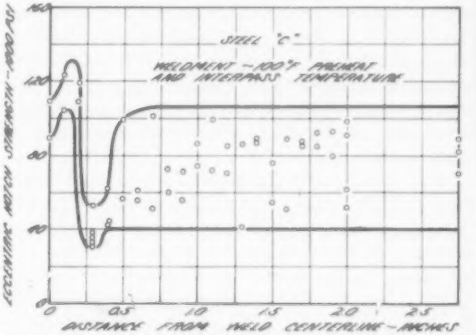


Fig. 14 Distribution of eccentric notch strength at −60° F.

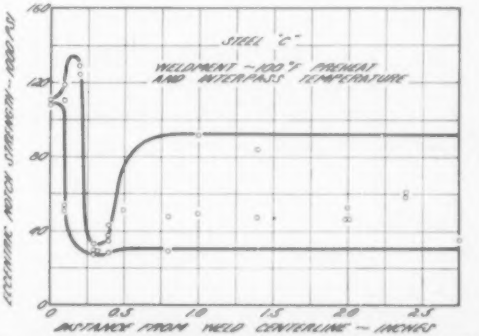


Fig. 15 Distribution of eccentric notch strength at −80° F.

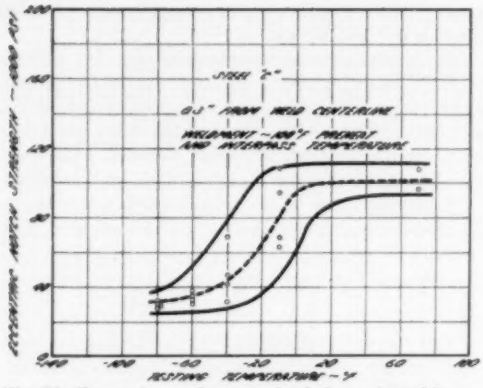


Fig. 16 Eccentric notch strength of the region of lowest ductility as a function of testing temperature

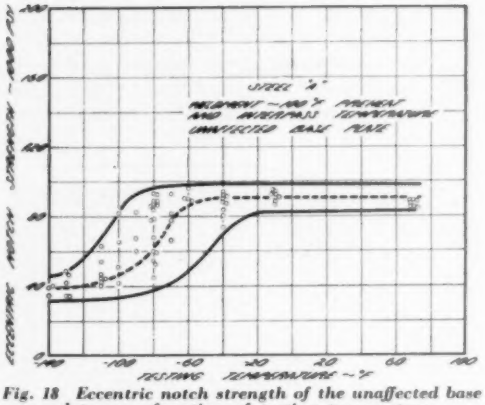


Fig. 18 Eccentric notch strength of the unaffected base plate as a function of testing temperature

showed constant properties up to the heat-affected zone where a pronounced minimum occurred at 0.3–0.4 in. from the weld center line. Closer to the weld the eccentric notch strength then rose to a maximum value in the structure near the junction of the heat-affected zone and the weld metal (approximately 0.15 in. from the weld center line). A somewhat lower notch strength was observed in the weld metal. At the location of the minimum in notch strength, the range of values was large for the higher testing temperatures but decreased with decreasing temperature to a very small range at −80° F., at which temperature material was evidently all embrittled. The maximum values of notch strength had approximately the same absolute value and also the same location for the various testing temperatures.

The values for the minimum (0.3 in.) position are shown in Fig. 16 as a function of testing temperature. Here it can be seen that the transition temperature is about −20° F. as compared to the −65° F. which was observed for the unaffected base plate.

The location of the maximum notch strengths (0.15 in. from weld center line) and the weld metal did not go through a transition in the range of testing temperatures which were used. However the relation between transition temperature and distance from weld center line can be represented as shown in Fig. 17. The zone of low ductility is definitely defined by its high transition temperature.

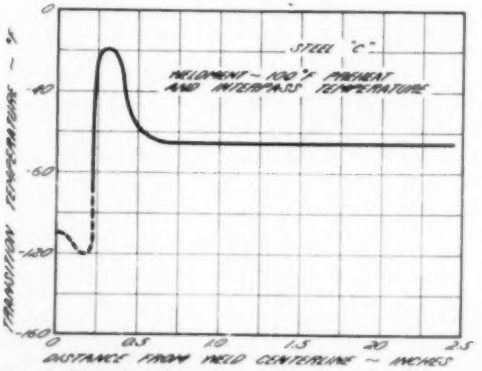


Fig. 17 Variation of transition temperature with distance from the weld center line

Steel A

The ductility minimum which was observed for the C steel at a distance of 0.3–0.4 in. from the weld center line probably would occur in weldments made of other steels. In order to check this an investigation was made on A steel weldments.

The distribution of values for the unaffected base plate tested at various temperatures, Fig. 18, was of the same type as that for the C steel except that the entire distribution was shifted to lower temperatures, the transition temperature being about −80° F. as compared with −65° F. for the C steel. The range of values for a given testing temperature was also smaller, particularly at the higher temperatures, indicating that the A steel is somewhat more uniform.

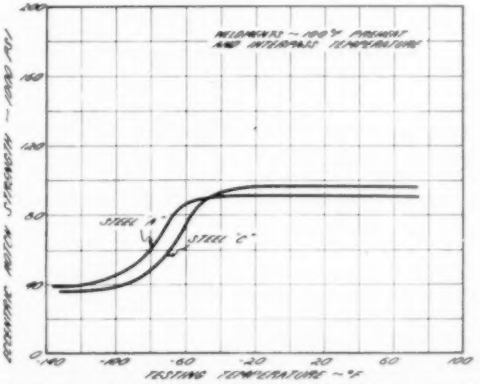


Fig. 19 Transition curves of the unaffected base plate of steels A and C

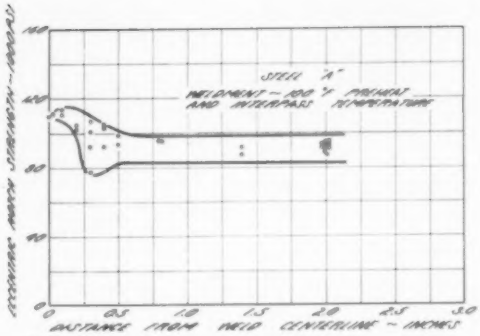

STEEL "A"
WELDMENT – 100° F. PREHEAT AND INTERPASS TEMPERATURE
ECCENTRIC NOTCH STRENGTH – KSI
DISTANCE FROM WELD CENTERLINE – INCHES

Fig. 20 Distribution of eccentric notch strength at −10° F.

A comparison of the average curves for the A and C steel base plates, Fig. 19, shows this lowering of the transition temperature. The difference in values at the higher testing temperatures is probably due to the higher tensile strength of the C steel* (see Table 1).

The distribution of notch properties, determined at −10° F., at various distances from the weld center line is shown in Fig. 20. The eccentric notch strength was fairly uniform across the plate. However, a slight minimum was observed at 0.3–0.4 in. from the weld center line and the slight maximum at the weld junction, 0.1–0.2 in. from the weld center line.

The distribution determined at −70° F., Fig. 21, showed the presence of a definite minimum at the location 0.3–0.4 in. from the weld center line. A maximum is also evident at the weld junction. The positions of the minimum and maximum are identical with those found for the C steel.

A number of tests on the A steel were made at various temperatures from the region of low ductility. From these tests, Fig. 22, it can be seen that the transition temperature is about −40° F.

A comparison of the average curve for this position

* The dependence of eccentric notch strength upon tensile strength rather than inherent ductility is valid only for ductile testing and material conditions. Under these conditions, the applied load goes through a maximum prior to specimen fracture. This maximum load is dependent upon the tensile strength of the material which then determines the notch strength.

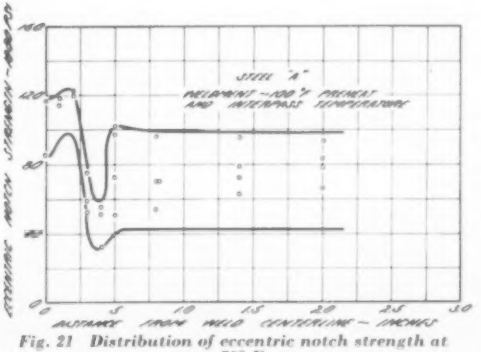

STEEL "A"
WELDMENT – 100° F. PREHEAT AND INTERPASS TEMPERATURE
ECCENTRIC NOTCH STRENGTH – KSI
DISTANCE FROM WELD CENTERLINE – INCHES

Fig. 21 Distribution of eccentric notch strength at −70° F.

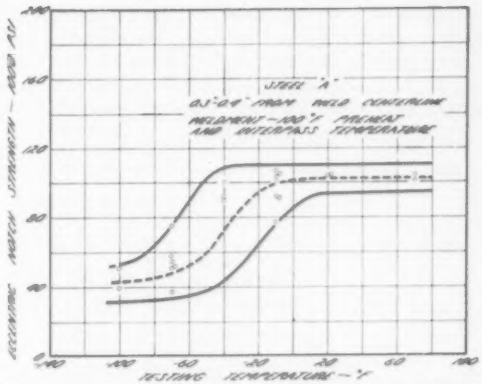

STEEL "A"
0.3"-0.4" FROM WELD CENTERLINE
WELDMENTS – 100° F. PREHEAT AND INTERPASS TEMPERATURE
ECCENTRIC NOTCH STRENGTH – KSI
TESTING TEMPERATURE – °F.

Fig. 22 Eccentric notch strength of the region of lowest ductility as a function of testing temperature

with a similar curve for the C steel, Fig. 23, shows that the curves are very similar, the curve for the A steel being about 20° F. lower than that for the C steel.

Preheat and Postheat

In order to investigate the possible beneficial effects of preheating and postheating, weldments of C steel were made using a 400° F. preheat and interpass temperature, and a postheat treatment was given to a C steel weldment which had been welded with a 100° F. preheat. The postheat treatment consisted of holding the weldment at 1100° F. for 1 hr., furnace cooling to 300° F., and air cooling to room temperature.

The results for the 400° F. preheat are given in Figs. 24–26. As was to be expected, the distribution of values for the unaffected base plate, Fig. 24, was practically identical to that for the 100° F. preheat. However the distribution of values across the weld determined at −80° F., Fig. 25, showed a definite improvement over the 100° F. preheat, in the region of

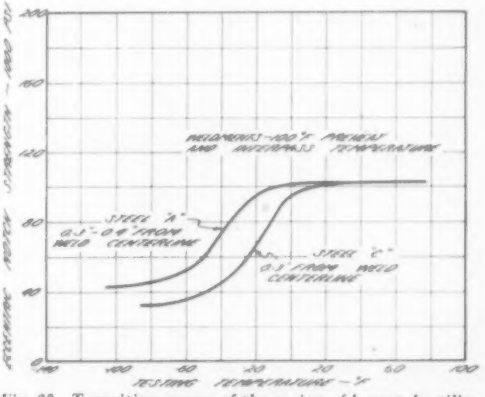

WELDMENTS – 100° F. PREHEAT AND INTERPASS TEMPERATURE
STEEL "A"
0.3"-0.4" FROM WELD CENTERLINE
STEEL "C"
0.3" FROM WELD CENTERLINE
ECCENTRIC NOTCH STRENGTH – KSI
TESTING TEMPERATURE – °F.

Fig. 23 Transition curves of the region of lowest ductility for steels A and C

low ductility. The variation of values in this region is greater and approaches that of the base plate.

This improvement can also be seen in Fig. 26, which shows the change of notch strength with temperature in the zone of low ductility. The transition temperature has been shifted to about −45° F. as compared with −20° F. for the 100° F. preheat.

The results for the 1100° F. postheat are given in Figs. 27–29. The distribution of values for the unaffected base plate, Fig. 27, showed some improvement over the weldments which were not postheated.

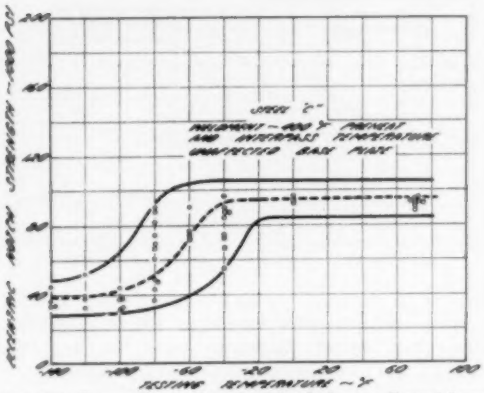


Fig. 24 Eccentric notch strength of the unaffected base plate as a function of testing temperature

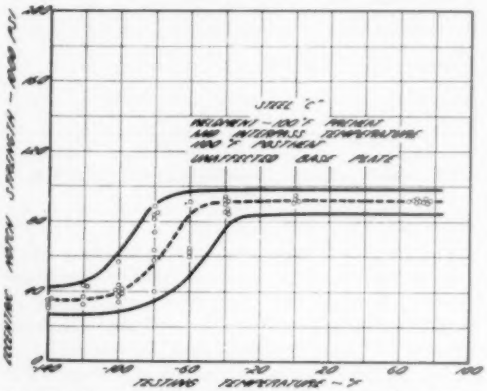


Fig. 27 Eccentric notch strength of the unaffected base plate as a function of testing temperature

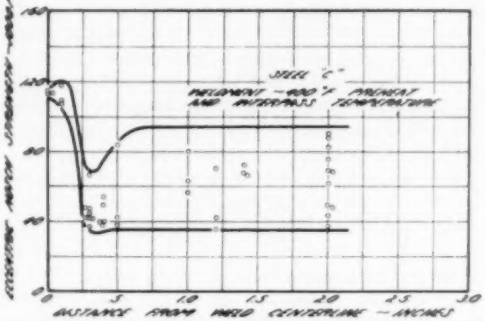


Fig. 25 Distribution of eccentric notch strength at −80° F.

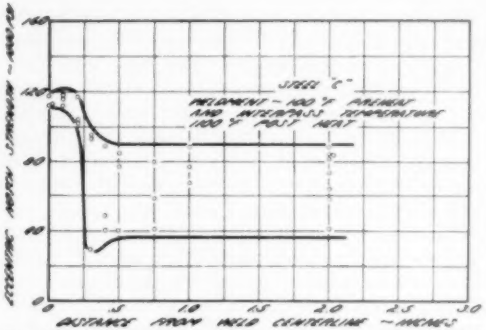


Fig. 28 Distribution of eccentric notch strength at −80° F.

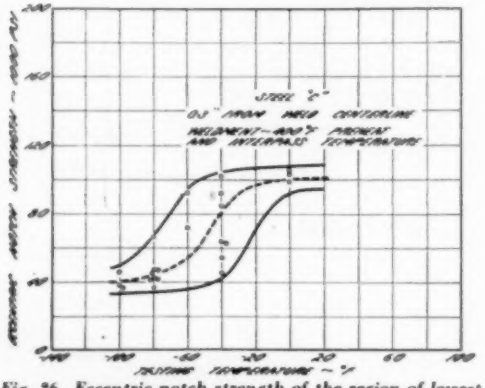


Fig. 26 Eccentric notch strength of the region of lowest ductility as a function of testing temperature

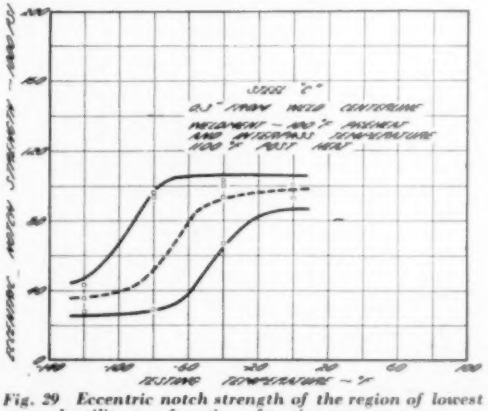


Fig. 29 Eccentric notch strength of the region of lowest ductility as a function of testing temperature

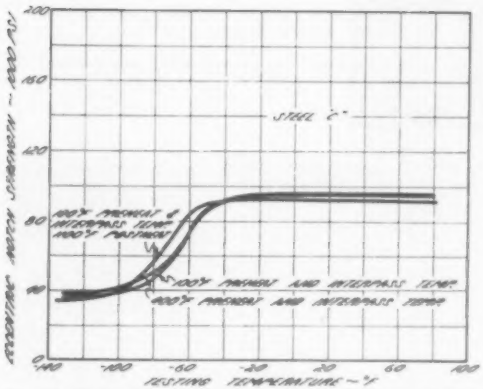


Fig. 30 Transition curves of the unaffected base plate of steel C for three welding conditions

The variation of values was less at the higher temperatures and the transition temperature was shifted to a lower temperature, −75° F. as compared with −65° F.

The distribution of notch strengths at −80° F., Fig. 28, shows that the minimum which was previously observed at 0.3–0.4 in. from the weld center line has been practically eliminated, that is, the material in this zone shows the same range of values as the unaffected plate.

The elimination of the minimum shows up as a lowering of the transition temperature for this region, Fig. 29. The transition temperature has been shifted to −70° F. as compared to −20° F. for the same region in the weldment which was not postheated, and −65° F. for the unaffected base plate in the weldment which was not postheated.

A comparison can now be made on the effects of pre- and postheating, respectively.

The transition curves for the unaffected base plates of C steel, Fig. 30, show that:

1. Data for the 100 and 400° F. preheat fit on the same curve.
2. The postheated plate has a lower transition temperature than the plates without postheat.
3. The notch strength at the higher testing temperature was lower for the postheated plate because of a slight softening of the material. This was shown also by the hardness tests.

A comparison of the distributions of notch strength across the welds determined at −80° F., Fig. 31, shows the improvement which has been made. The 400° F. preheat shows a definite improvement and the postheat treatment virtually eliminates the region of low ductility.

This improvement is even more noticeable in a comparison of the transition curves for this region, Fig. 32. The transition temperature of −20° F. for the 100° F. preheat was shifted to −45° F by the 400° F. preheat, and to −70° F. by the postheat treatment.

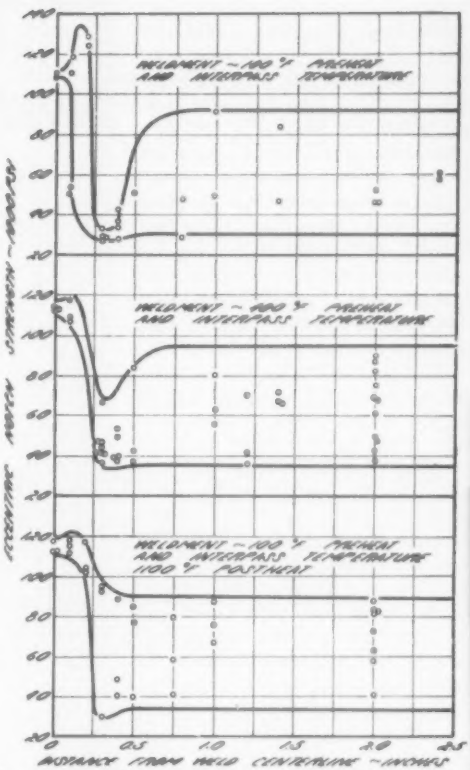

WELDMENT – 100° F. PREHEAT AND INTERPASS TEMPERATURE
WELDMENT – 100° F. PREHEAT AND INTERPASS TEMPERATURE
WELDMENT – 100° F. PREHEAT AND INTERPASS TEMPERATURE 100° F. POSTHEAT

Fig. 31 Distribution of eccentric notch strength of C steel at −80° F. for three welding conditions

Metallurgical Structure

A macrograph and a series of photomicrographs representative of the various structural zones are shown in Fig. 33 for the C steel weldments made with 100° F. preheat.

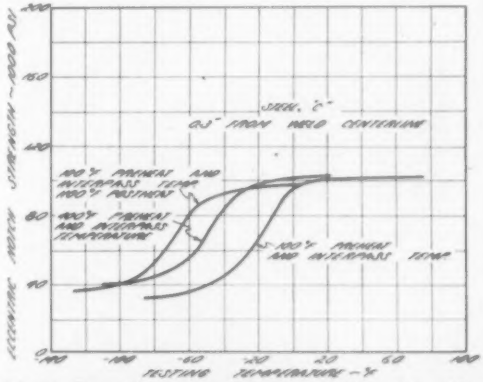

STEEL C
0.3" FROM WELD CENTERLINE
100° PREHEAT AND INTERPASS TEMP. 100° POSTHEAT
100° PREHEAT AND INTERPASS TEMPERATURE
100° PREHEAT AND INTERPASS TEMP.

Fig. 32 Transition curves of the region of lowest ductility for three welding conditions

The macrograph shows the over-all structure of the weld and the heat-affected zone; it can be seen that each weld pass gives rise to a heat-affected zone which combines with the zones from the other passes to give the over-all heat-affected zone.

The series of photomicrographs are representative of the structures encountered on the center line of the plate at various distances from the vertical center line of the weld.

The weld metal, Fig. 33 (*b*), is a fine-grained structure which has been obviously refined by the last weld passes.

The weld junction is defined by the sudden large change in grain size at 0.08 in., Fig. 33 (*c*). With increasing distance from the weld center line, the grain size of this structure which was cooled from above the upper critical (Ac_3) decreases, Fig. 33 (*d*). The structure resulting from transformation from the temperature range between the upper (Ac_3) and lower critical (Ac_1), Fig. 33 (*e*), merges into the structure of the parent plate as shown in Figs. 33 (*f*) and 33 (*g*). There seems to be no difference in structure between the structure of the critical zone (0.3–0.4 in. from the weld center line) and that of the parent plate when examined either at 100 or at 2000 magnifications, as shown in Fig. 34.

Photomicrographs were also made of the 0.3-in. position for the C steel weldments which were preheated and postheated, respectively. These, Fig. 35, also seem to have the same structure as the unaffected base plate.

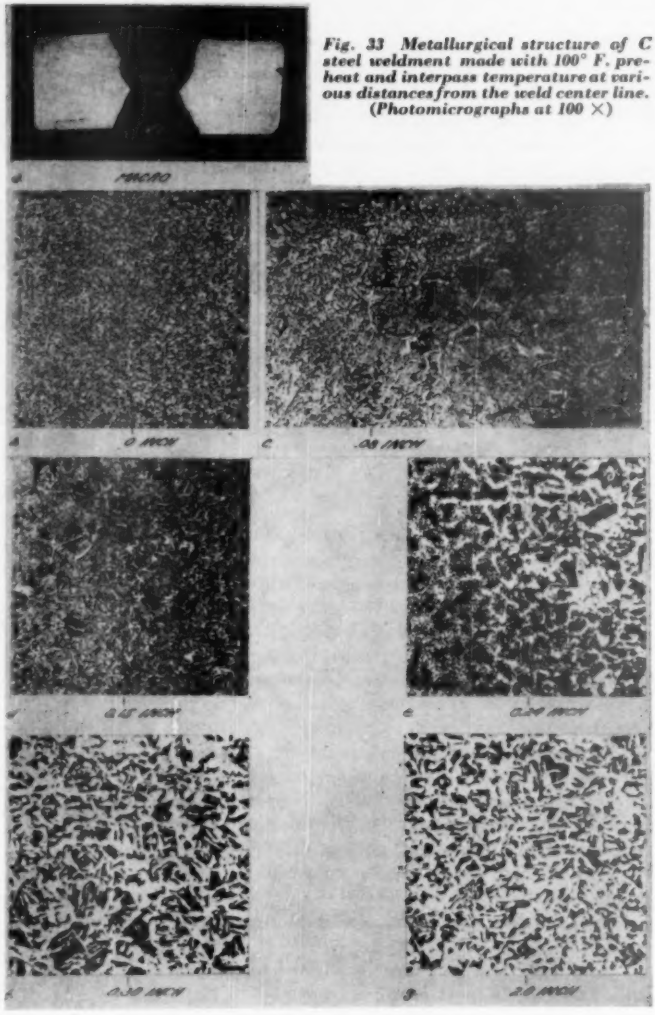
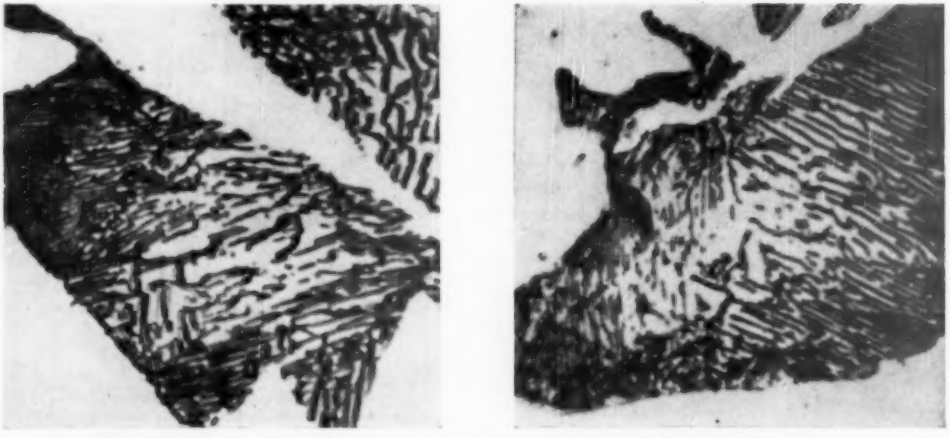


***Fig. 33** Metallurgical structure of C steel weldment made with 100° F. preheat and interpass temperature at various distances from the weld center line. (Photomicrographs at 100 ×)*



0.3 in. from weld center line. 2000 ×

Unaffected base plate. 2000 ×

***Fig. 34** Microstructures of unaffected base plate and critical zone in C steel weldment made with 100° F. preheat and interpass temperature. Picral etch*

Microhardness Tests

Microhardness tests were made on all of the weldments with a Tukon Hardness Tester using a 136° Diamond Pyramid Indentor and a 1000 gm. load. The indentations were about 0.1 mm. (0.004 in.) long and were spaced at intervals of 0.01 in.

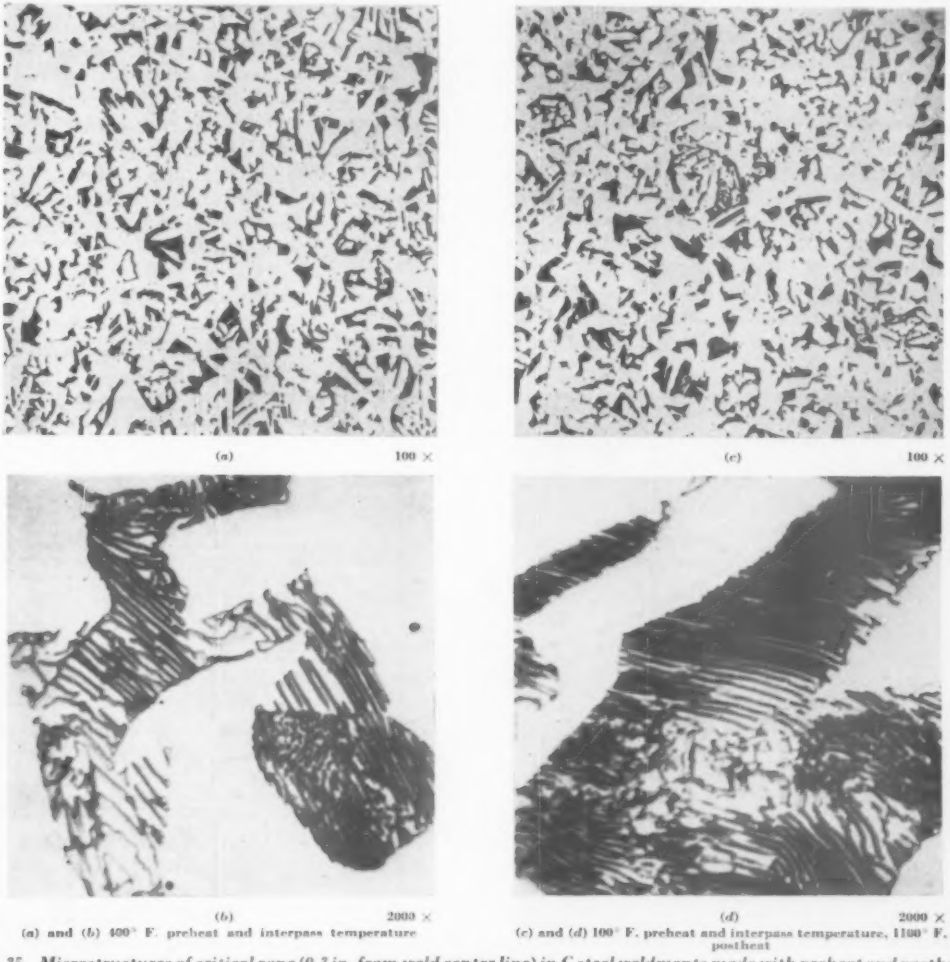
Microhardness surveys were made across representative sections of all the welds at the center of the plates. These results are shown in Fig. 36. The greatest variation in hardness was shown by the C steel weldment with 100° F. preheat. A number of hardness peaks were found, the highest one being at the weld junction. The other peaks were due to the composite heat-affected zone caused by the six weld passes. To compare this scale with Rockwell hardness tests the maximum hardness of 240 on the DPH scale corresponds to about Rockwell C20, and the minimum hardness of 150 on the DPH scale corresponds to about Rockwell B80.

The C steel weldment with 400° F. preheat had almost a flat hardness distribution with no prominent peaks.

The hardness distribution curve for the weldment which was postheated was similar to that of the weldment without postheat except that the peaks were lowered from a maximum of DPH 240 to DPH 200. The over-all level of the whole curve was also lowered indicating some softening of the entire plate.

The hardness curve for the A steel weldment was similar to that for the C steel weldment, but the peaks were lower and the over-all curve was lower.

A more detailed investigation was made of the C steel weldment with 100° F. preheat. Surveys were made across the thickness of the plate at various distances from the weld center line. From these surveys a model, Fig. 37, was constructed which shows the over-all hardness picture and the complexity of the heat-



(a) 100 ×

(c) 100 ×

(b) 2000 ×

(a) and (b) 400° F. preheat and interpass temperature

(d) 2000 ×

(c) and (d) 100° F. preheat and interpass temperature, 1100° F. postheat

Fig. 35 Microstructures of critical zone (0.3 in. from weld center line) in C steel weldments made with preheat and postheat, respectively. Picral etch

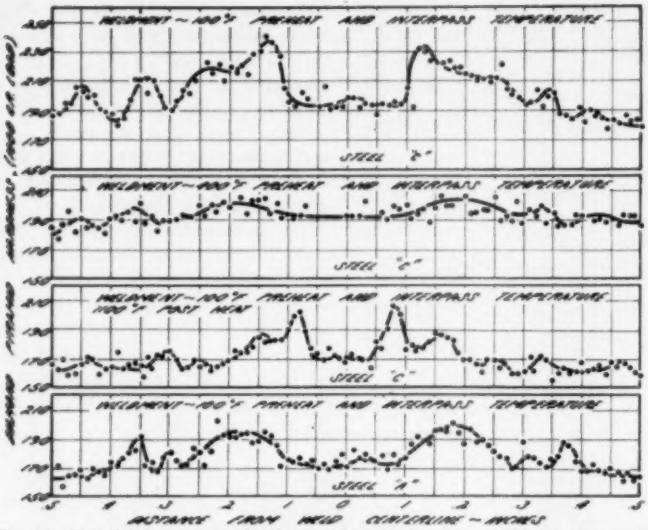


Fig. 36 Distribution of microhardness values at the center of $^3/_4$-in. plate weldments of steels C and A

affected zone. The sketch in the figure shows the position of the weldment and the six weld passes. The effect of each weld pass can be seen as a peak in hardness, the zones from each peak blending together to give the over-all picture. The zone of low ductility lies in the region behind the hardness peaks where the hardness distribution is relatively flat.

A few sections from the model at various distances from the weld center line, Fig. 38, show the magnitude of the peaks especially at 0.08 and 0.12 in. from the weld center line.

Fig. 37 Microhardness survey on a $^3/_4$-in. plate weldment of steel C (100° F. preheat and interpass temperature)

Temperature Measurements

The results of the temperature measurements made during the welding of the C steel are given in Figs. 39–41. In Fig. 39, the maximum temperatures reached during the welding process are shown as a function of the distance from the weld center line for the weldments with 100 and 400° F. preheats, respectively. In the region of low ductility (0.3–0.4 in. from weld center line) the temperature evidently never reached the lower-critical temperature (Ac_1) for either weldment.

In Fig. 40, the complete heating and cooling history of the region of low ductility is given for both welding conditions. For each weldment the peak temperatures decreased for the last three weld passes. The 400° F. preheat weldment showed a higher peak temperature for the first two passes than the 100° F. preheat weldment.

A comparison of the heating and cooling cycles for the first pass for the two welding conditions, Fig. 41, shows that the 100° F. preheat weldment has a faster cooling rate. This difference in cooling rate can be shown for all of the weld passes.

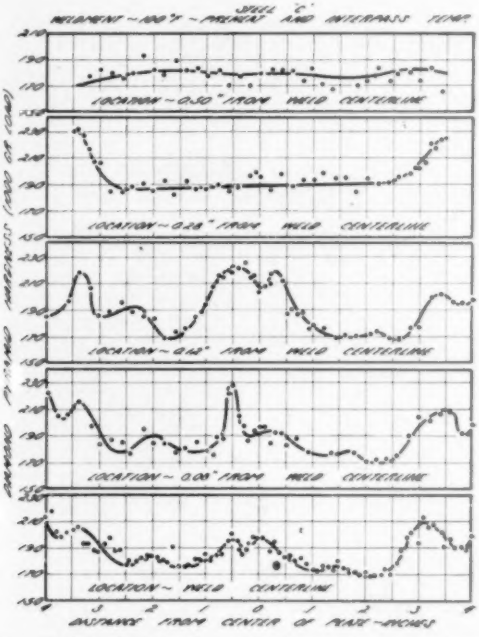


Fig. 38 Distribution of microhardness values at various distances from the weld center line

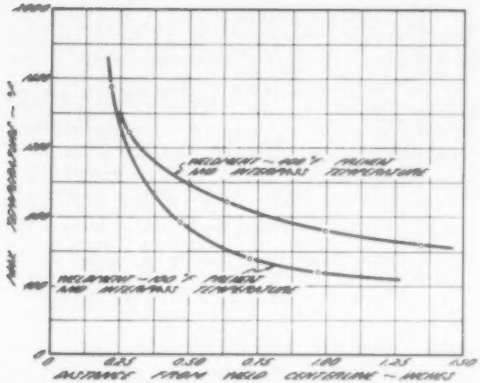


Fig. 39 Maximum temperatures reached during welding for two welding conditions

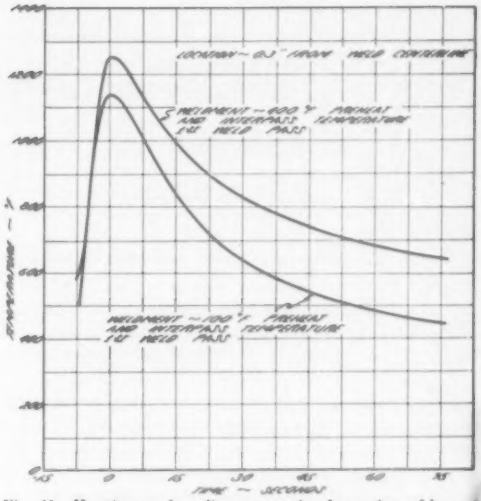


Fig. 41 Heating and cooling curves in the region of lowest ductility for two welding conditions

Specimen Size

The changes in notch strength and hardness were very rapid as the distance from the weld center line was increased from zero to 0.5 in. Consequently, a smaller specimen than the specimen which was used might be expected to show up greater differences in notch strengths.

A few specimens were made of A steel with 0.212 in. outside diameter and 0.150 in. notch diameter. The area of the notched section was thus one-half of that of the standard specimen. Tests were taken from the weld metal, base plate and the zones containing the maximum and the minimum. The specimens were tested at −70° F. and the results are shown in Fig. 42 superimposed on the results of the standard specimens (taken from Fig. 21).

In the zone of minimum ductility the notch strengths of the smaller specimens fell in the range of values of the

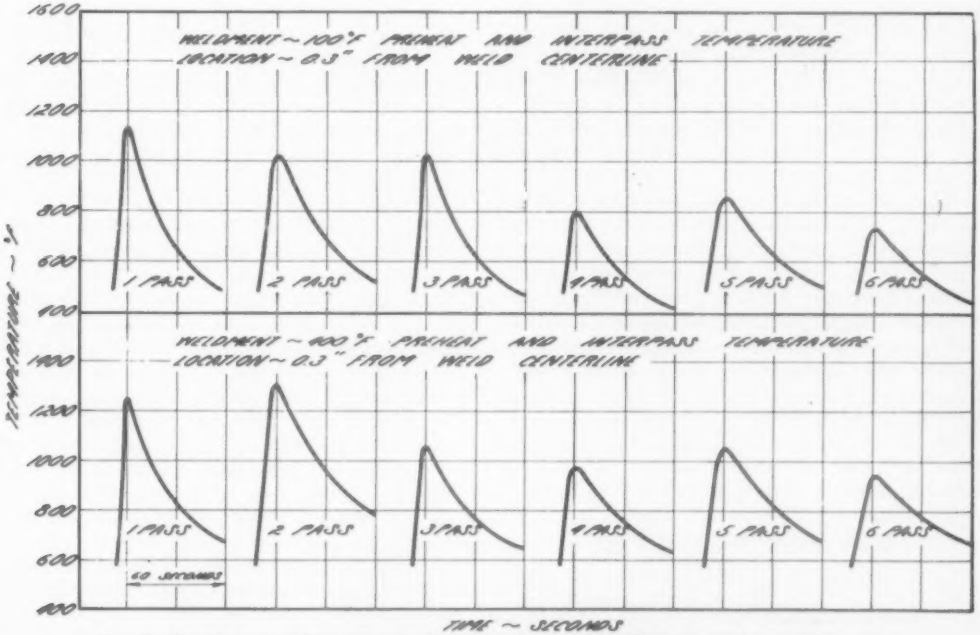


Fig. 40 Heating and cooling curves in the region of lowest ductility for two 6-pass weldments

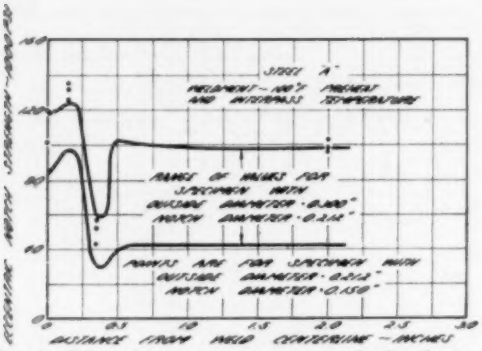


Fig. 42 Effect of specimen section size on the distribution of eccentric notch strength at −70° F.

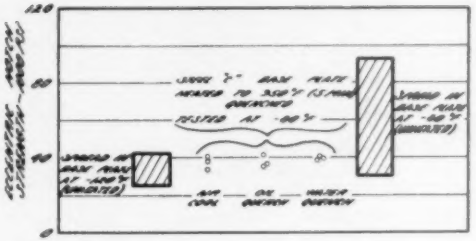


Fig. 43 Effect of subcritical heating and cooling on the eccentric notch strength of unaffected base plate

standard specimen. In the other positions the smaller specimens gave higher values. However, a higher notch strength would be expected in these regions because of the slightly smaller effective notch sharpness,* and the regular section size effect. The difference, however, was small. In the region of low ductility the fiber in maximum tension controls the reaction of the specimen so that the above-mentioned factors have a negligible effect.

This specimen then offers no advantages over the standard specimen when taken from the center of the plate.

Subcritical Heating

The temperature measurements that were made indicated that the embrittled zone for the 100° F. preheat weldment was cooled from about 1000° F. in the first three weld passes. An attempt was made to duplicate the embrittlement shown in the region of low ductility by means of heating and cooling of base plate. Blanks of C steel base plate were heated to 950° F., held for 5 min. and cooled to give three different cooling rates, air cool, oil quench and water quench. Standard specimens were made and tested at −80° F. The notch strengths for all three rates of cooling were low, Fig. 43, and when compared to the spread of values for the base plate at −80° F., it can be seen that the material was substantially embrittled by this heating and cooling. The range of values found previously for base plate tested at −120° F. will encompass all of these values so that in effect the transition temperature has been raised approximately 40° F. by these subcritical heating and cooling cycles. This is comparable to the change in transition temperature in the C steel weldment where the transition temperature of −65° F. in the unaffected base plate was raised to −20° F. in the critical region, a change of about 45° F.

DISCUSSION OF RESULTS

The temperature measurements which were made during welding on both 100 and 400° F. preheat weldments showed that the zone of low ductility was not heated above the lower critical temperature (Ac_1). Also, no differences in microstructure could be distinguished in the structures in the critical zone and in the unaffected base plate.

The hardness tests cannot be correlated with the notch strength. The peak in hardness for each weldment was associated with the maximum in notch strength, but the minimum in notch strength occurred in a region where the hardness variations were leveling off. Therefore, hardness cannot be used as a measure of ductility.

An investigation[4] on the annealing of low-carbon steel has shown that there are three factors which change the properties of a steel when it is cooled. The first of these is the gamma-alpha transformation which results in a reduced grain size and higher hardness. If the cooling is sufficiently fast a martensitic structure is formed which on tempering still remains relatively hard and has a ductility higher than that of pearlite. This may then account for the maximum in notch strength which was observed near the weld junction.

The remaining factors may account for the ductility minimum which was observed. The first, the solution effect, is essentially the formation of a supersaturated solid solution of carbon in ferrite which is harder than the equilibrium mixture. Associated with this is the other factor, aging. It results from precipitation of carbon or carbides from the supersaturated solution. The solid solution factor has its maximum effect on fast quenching from the lower critical. However, the aging effect would be expected to have a maximum effect at some critical point of time and temperature, beyond which the effects would be decreased. These factors have been shown to produce an increase in hardness and an accompanying decrease in ductility in low-carbon steel.[4]

The combined effects of the solution and aging have also been shown by Pollard[5] to increase the tensile strength and lower the ductility of low-carbon mild steel. Pollard refers to this phenomenon as "quench aging."

The solid solution and aging effects can occur simultaneously at the cooling rates found in the region of low ductility in the weldments. The heating and cooling curves showed that the temperature did not reach the

* Notch sharpness is defined as the ratio of the radius of the cross section at the notch to the notch radius.

lower critical and the cooling rates were not fast enough to obtain the maximum solid solution effect. However, the time-temperature relations which are encountered in the critical zone for a weldment with 100° F. preheat may be those which would cause maximum embrittlement. The 400° F. preheat weldment had a slower cooling rate which would permit less of the solution and aging effects and thus explain the improvement in the critical region. The almost complete elimination of the critical region by the postheat treatment would then be attributed to "overaging" that is, the aging effect was carried past the critical point.* According to this hypothesis, varying combinations of preheat and postheat would be expected to give different degrees of improvement depending upon whether the solution and aging effects were carried to, or past, the critical point.

CONCLUSIONS

1. A zone of low ductility was detected in the welded plate, at a distance of 0.3–0.4 in. from the weld center line for both C steel and A steel welded with 100° F. preheat.

2. A 400° F. preheat improved the ductility in the critical zone, lowering the transition temperature from −20 to −45° F.

3. A 1100° F. postheat practically eliminated the zone of low ductility, the transition temperature being lowered to −70° F.

4. Temperature measurements showed that the occurrence of this region of low ductility is due to some subcritical temperature phenomena which may be the supersaturation and precipitation of carbon or carbides.

* This effect of overaging was observed for the low-carbon steel.[4]

ACKNOWLEDGMENTS

The authors are indebted to the Ship Structure Committee for permission to publish this information and wish to acknowledge the interest and help of Dr. F. Jonassen, Technical Director of the Committee on Ship Steel.

The authors are also indebted to Dr. W. M. Baldwin, Jr., who directed the work, Dr. G. Sachs who initiated the investigation and A. W. Dana and Dr. S. I. Liu who performed many of the tests.

Acknowledgment is also given to the Batelle Memorial Institute for welding the plates and conducting the temperature measurements and particularly to C. B. Voldrich, P. J. Rieppel, R. W. Bennett and M. Forman for their aid.

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Work of Ship Structure Committee

(*Continued from page 49-s*)

great need for further study of the conditions which affect the resistance of welded ships to fracture. The welded ship problem will not be solved until completely safe, all-welded ships can be mass produced. It is my sincere hope and belief that the Ship Structure Committee and this SOCIETY can make important contributions to the solution of this problem.

I wish to thank the AMERICAN WELDING SOCIETY for its continuing interest in the Ship Structure Committee and for having assigned a full day of its Technical Session at this Annual Meeting, to the Symposium on Ship Structure Research.

Discussions by Pellini and Hartbower

(*Continued from page 58-s*)

mens. That the presence and sharpness of notches (natural or imposed) are factors leading to failure is axiomatic but, nevertheless, worth restating. While a qualitative evaluation of steels based on the inherent resistance to the propagation of a material crack is useful, the fact that the performance of a structure is very much dependent upon the precrack stage cannot be overlooked as a complication to the problem of correlation.

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Effect of Fatigue on Transition Temperature of Steel

Fatigue cracks develop and propagate at cyclic stresses below the endurance limit and such cracks materially raise transition temperature. In some steels static prestraining also raises transition temperatures

by J. M. Lessells and H. E. Jacques

Abstract

This report concerns an investigation to determine if prior fatigue would affect the transition temperature curves in impact of ship steels. Tests were made on two shipbuilding steels, B and W, the greater amount of work having been done on Steel B.

A combination fatigue-impact specimen was designed and used. This specimen was round with a circumferential notch and could be tested in impact by sawing off the tapered ends necessary for holding in the fatigue machine.

As testing proceeded, it was found that fatigue cracks were developing at the base of the notch both above and below the endurance limit. When specimens were cyclically stressed so as to avoid fatigue cracks, the resulting transition curve showed little deviation from the original curve presumably due to the low stress of the prior fatigue.

A series of specimens of Steel B were prestrained in tension prior to testing in impact with a marked shift of the transition curve resulting.

INTRODUCTION

IN RECENT years a number of investigations have been undertaken to deal with the problem of fractures of ocean-going ships. These investigations have sought to study the nature and causes of these fractures and to develop small laboratory tests which may determine the suitability of individual heats for shipbuilding steel at the time of manufacture.

In service a ship is subjected to many different forms of stress which undoubtedly alter the properties of the structural steel. Unfortunately no comprehensive study has been made to date which undertakes to measure qualitatively and quantitatively the stresses experienced by a ship at sea.

The Bureau of Ships of the Navy Department has been greatly concerned with this problem of fracture and has sponsored this project to investigate the effect of one form of service loading on the strength characteristics, specifically the effect of cyclic stress or fatigue on the impact properties of shipbuilding steel.

After the project was under way, it was thought advisable to determine also the effect of prestraining in tension on the impact properties. These tests were incorporated in the test schedule and the results are included in this report.

This work was carried out under Bureau of Ships Contract NObs-25391. It was conducted at Massachusetts Institute of Technology with Prof. John M. Lessells as supervisor and Herbert E. Jacques as investigator.

EXPERIMENTAL WORK

Choice of Test

Rayflex Machine. In the early stages of this investigation it seemed desirable to cyclically stress a square specimen of Charpy size either with or without the notch. At this time the use of the Rayflex Fatigue Machine appeared promising. This machine produces bending by means of two alternating-current magnets which alternately attract and repel the ends of the specimen. The frequency of the magnets is variable and is set to give resonant vibration of the specimen.

There were three disadvantages associated with the use of this machine which led to its abandonment in favor of the R. R. Moore rotating beam fatigue machine.

First, specimens had to be from 18–24 in. long to give a sufficient beam length. Out of each length only one Charpy specimen would be procured. This would necessitate an enormous supply of material and result in high cost of specimen preparation.

Secondly, it was impossible to produce maximum bending stresses of over 37,000 psi. with a specimen of constant cross section. The remedy for this would have been to attach steel weights to the ends of the specimens so as to increase the bending moment at the test section without increasing its size.

And lastly, exceptional care would have had to be taken to insure that the specimens were as square as possible. It was observed that in the preliminary tests the specimens vibrated in an elliptical pattern rather than straight up and down. The major axis of this ellipse coincided with the longer diagonal of the cross section.

Round-Notched Impact Specimen. It was then

J. M. Lessells is Associate Professor of Mechanical Engineering and H. E. Jacques is Research Investigator, Massachusetts Institute of Technology, Cambridge, Mass.

Presented at the Thirtieth Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

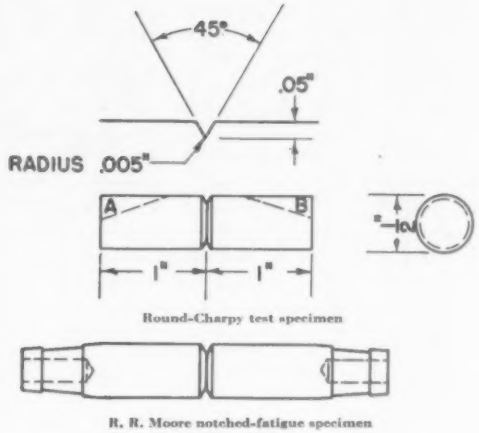

Figure 1

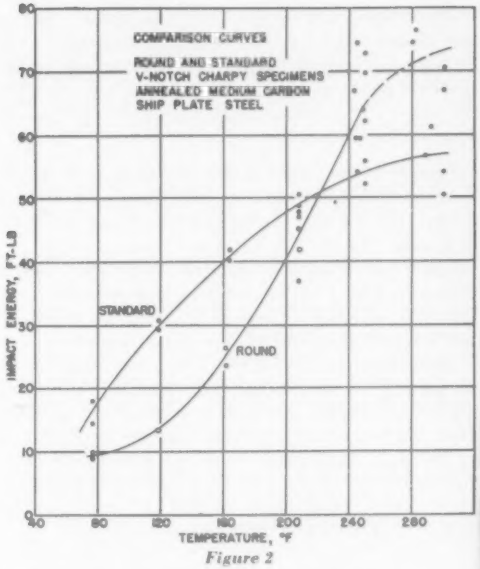

Figure 2

learned that Dr. C. H. Lorig,[1] of Battelle Memorial Institute, had used a round-notched specimen in impact which gave results comparable to the standard V-notch Charpy specimen. It was thought possible to adapt this specimen to a rotating beam type of fatigue test in which the fatigue specimen could be machined to the impact form of specimen.

Dr. Lorig kindly supplied the specifications of his specimen and instructions for its preparation. Drawings of the impact and fatigue specimens are shown in Fig. 1. Details of the preparation of this specimen are given in the Appendix.

Since Dr. Lorig had not specified that the round-notched specimen was comparable to the V-notch Charpy for medium carbon steels of shipbuilding quality, it was thought desirable to make some comparative impact tests of the specimens using such a steel.

In order to conserve the project steels, the material selected for the comparative tests was a medium carbon shipbuilding steel meeting the requirements of Navy grade 4885. Several small $^3/_4$-in. plates of this material were obtained from the Boston Navy Yard. These plates were annealed before using. The results of the comparative impact tests are shown in Fig. 2.

After verification had been obtained of the suitability

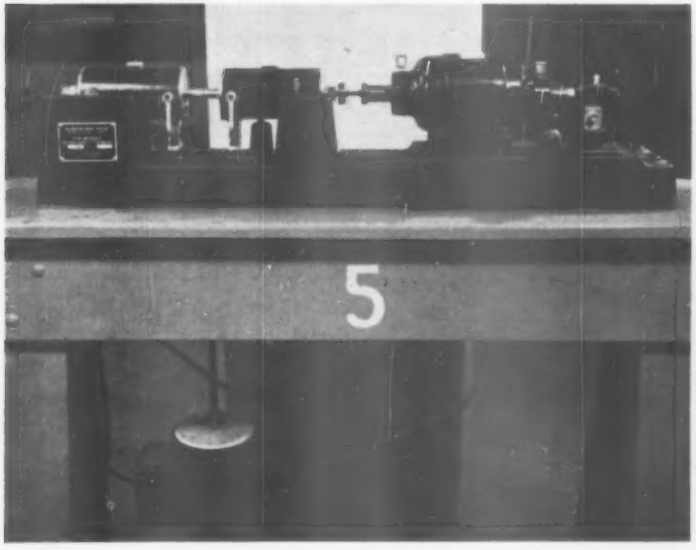

Fig. 3 R. R. Moore rotating beam fatigue machine

Fig. 4 Charpy impact machine

of the round-notched impact specimen, a test schedule was prepared and the experimental work begun. The results included in this report are based entirely on the specimen shown in Fig. 2.

Procedure

Specimens were stressed cyclically in an R. R. Moore Rotating Beam Fatigue Machine (Fig. 3). A detailed account of the use of this machine is given in the Appendix.

The Charpy impact tester used in these tests is shown in Fig. 4. This machine is of standard construction and has an energy capacity of 225 ft.-lb. and a striking velocity of 17.4 ft. per second.

Specimens were held at the desired test temperatures in thermos bottles for at least 30 min. Not more than 5 sec. elapsed between removal of the specimen from the temperature bath and fracture.

The test temperatures were produced as follows: (*a*) Below 32° F., dry ice and carbon tetrachloride; (*b*) 32° F., ice and water mixture; (*c*) 32 to 160° F., water; and (*d*) above 160° F., mineral oil.

Experimental Results—Steel B

The first and major portion of the work was done on Steel B. This steel is an 0.18 C, semikilled, hot-rolled shipbuilding steel. This steel was received in $^3/_4$-in. plate form and was tested as-received. The chemical analysis and mechanical properties of this steel are given in the Appendix.

Fatigue Tests. *S–N* diagrams were obtained for Steel B with notched and standard smooth specimens. These curves are shown in Fig. 5.

The stresses shown for the notched specimens are the nominal stresses based on the specimen diameter at the root of the notch.

For this form of notch the strength reduction factor for Steel B is 1.2 (endurance limit for unnotched specimens divided by endurance limit for notched specimens; 31,000/25,800 = 1.2).

Impact Tests. A summary of all impact tests on Steel B is shown in Fig. 6. The detailed results of tests on unstressed specimens of Steel B are shown in Fig. 7.

Overstressing Tests. After the *S–N* diagram had been obtained, a series of notched fatigue specimens were subjected to a stress 15% over the notched endurance limit and a cycle ratio of 50%, i.e., half the number of cycles to produce failure at that stress.

When the notched endurance limit had been determined as 25,800 psi., a series of specimens were stressed at 29,700 psi. for 105,000 cycles. These specimens were altered to impact form and tested at various temperatures. The results are shown in Fig. 8.

At this time it was observed that all the specimens exhibited a dark band about 0.02 in. wide on the fracture surface adjacent to the base of the notch. It was thought that these bands might represent fatigue cracks. This proved to be the case. The methods

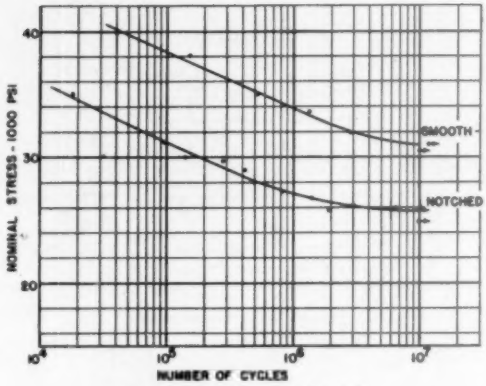

Fig. 5 S–N diagram, Steel B

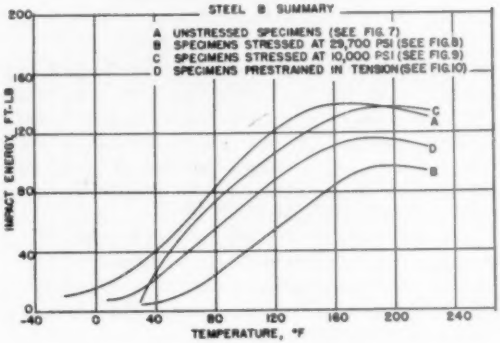

Figure 6

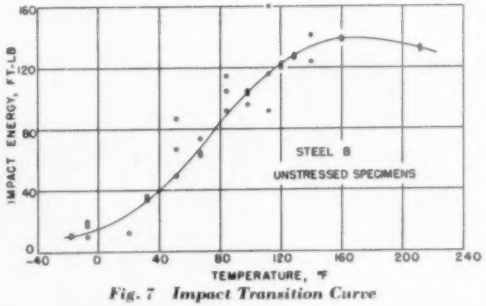

Fig. 7 Impact Transition Curve

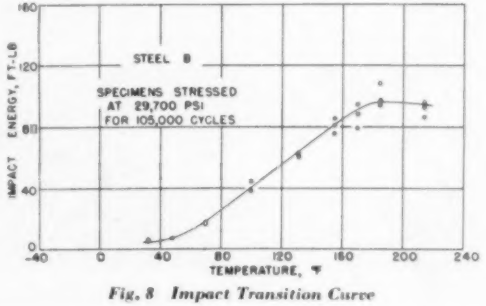

Fig. 8 Impact Transition Curve

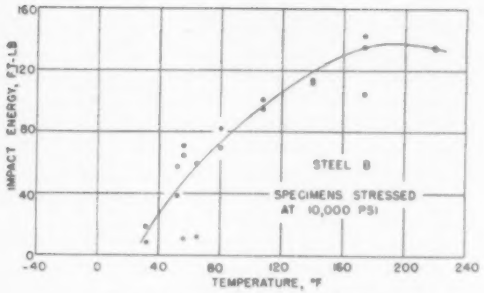

Fig. 9 Impact Transition Curve

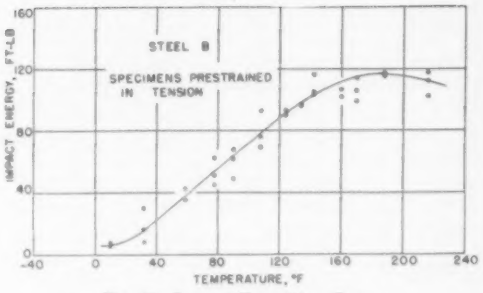

Fig. 10 Impact Transition Curve

used in the detection and measurement of the cracks are described in the Appendix. The dark bands are shown in Fig. 15.

Similar dark bands both above and below the endurance limit have been reported by MacGregor and Grossman[2] although they concluded that the bands did not represent fatigue cracks.

Fatigue Crack Investigation. The original object of this investigation was to determine the effect of cyclic stress alone on the transition temperature. The contribution of a fatigue crack to transition temperature shift would be impossible to evaluate. Therefore, the next phase of the project was directed toward investigating the occurrence of fatigue cracks with the object of avoiding them.

Specimens were run for various numbers of cycles at lower stresses and then sectioned and measured as described in the Appendix.

At first it was thought necessary to explore the region on the S–N diagram down to the vicinity of the endurance limit only. The numbers of cycles were reduced to as low as 2000 cycles. All specimens tested showed measurable cracks.

It was then evident that stresses below the endurance limit must be explored. This was done and cracks were evident until the stress was reduced to 10,000 psi., about 40% of the endurance limit. There was no evidence of cracking in two specimens run at 10,000 psi. for 1.75 million cycles.

Fatigue Crack Occurrence. The data on fatigue crack occurrence and magnitude are shown in Fig. 11. Some discussion of these curves is desirable.

It can be seen that the curves for the two higher stresses are not straight and intersect, while the curves for the lower stresses are quite regular. This is thought to be an effect of testing technique. When the crack investigation was started, the object was to find a combination of stress and numbers of cycles which would not result in the occurrence of fatigue cracks. In doing this, test specimens which ran reasonably free from vibration were deemed satisfactory for this purpose. However, as the existence of fatigue cracks below the endurance limit became evident, it was seen that a previously unreported phenomenon was occurring. Therefore, in order to accumulate data which would be as accurate as possible, only those specimens which would run perfectly smoothly were used in the investigation of the lower stresses. The plot for 21,500 psi. is a good example of data from vibrationless specimens.

Final Stressing. Since no fatigue crack had developed in two specimens run at 10,000 psi. for 1.75 million cycles, it appeared safe that a series of specimens could be stressed at 10,000 psi. for one million cycles without danger of cracking.

This was done and the specimens tested in impact. The results are shown in Fig. 9.

Prestraining in Tension. In addition to prestressing by cyclic stress, a series of notched specimens was subjected to a static tensile load before testing in impact.

A complete tension test was conducted on the notched specimen. The description of this test is included in the

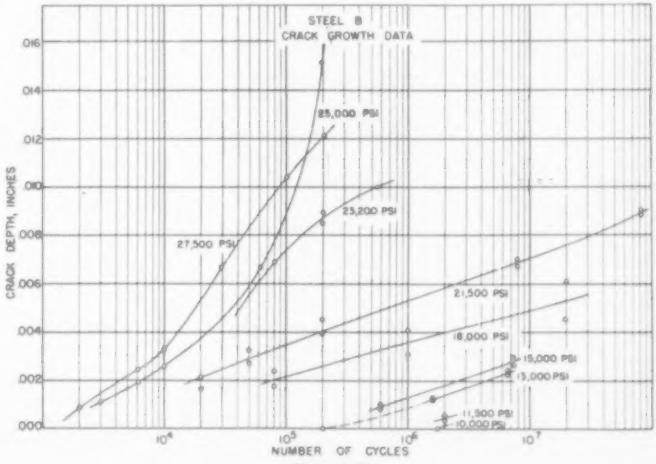

Figure 11

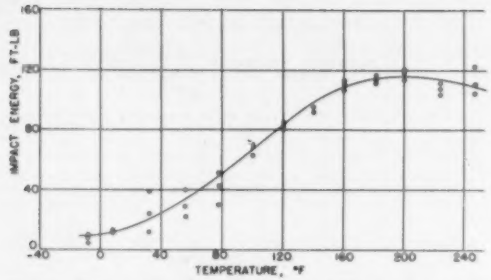

Fig. 12 Impact tests on Steel W, round Charpy specimens (unstressed)

Appendix. The test specimens were loaded to 55,000 psi. which should have resulted in a reduction of the specimen diameter at the root of the notch of 1% or 0.004 in. For all the specimens prestrained in tension, this reduction in diameter was between 0.003 and 0.004 in.

The specimens were altered to impact form and tested at various temperatures as before. These results are shown in Fig. 10.

Cyclograph Magnetic Core Loss Machine. Some of the fatigue work on Steel B was done in conjunction with a DuMont Cyclograph, an electronic machine for determining the amount of magnetic core loss. This work was performed by C. P. Moore,[3] a graduate student at M.I.T.

Attempts were made to correlate Cyclograph data with the growth of the fatigue crack and shift of the transition curve due to cyclic stress. This investigation was largely unsuccessful and further discussion is unwarranted.

Experimental Results—Steel W

The investigation of Steel W was conducted in a manner similar to that of Steel B.

The results of impact tests on round-notched specimens of Steel W are shown in Fig. 12. The results of fatigue tests on standard smooth and notched specimens of Steel W are shown in Fig. 13. Fatigue cracks occurred in Steel W as in Steel B. The occurrence of the cracks was investigated in the same way. The crack growth plot for Steel W is shown in Fig. 14.

These data indicate that specimens of Steel W would have to be prestressed at or about 10,000 psi. to avoid fatigue cracks. Since this stress produced little effect on the transition temperature of Steel B, it was decided that further investigation of Steel W was not warranted.

*Discussion of Results of Steel B.** Both prestressing by fatigue and prestraining by tension have shifted the transition curve upward in temperature.

The curve of specimens stressed at 29,700 psi. (Curve B, Fig. 6) shows the largest shift, about 75° F. However, this curve is partially invalidated because of the presence of a fatigue crack. Whether or not the major factor in the shift is due to the prestressing alone is in doubt.

When the fatigue stress was reduced to 10,000 psi. to avoid cracking, the resulting curve (Curve C, Fig. 6) shows little shift, only about 10° F. Apparently this stress, which is only 40% of the endurance limit, is too low to give any definite effects.

The curve for specimens prestrained in tension (Curve D, Fig. 6) lies between the two previous ones and reveals a shift of about 30° F. from the original Curve A.

The maximum energies of Curves B and D are appreciably lower than those of the original Curve A. Curve C shows no reduction in maximum energy.

Aside from the expected ascending order of Curves A, C and B, it does not appear possible to deduce any correlation between them. Test of specimens prestrained in tension at other stresses should prove valuable. It is expected that these curves would also be in an ascending order.

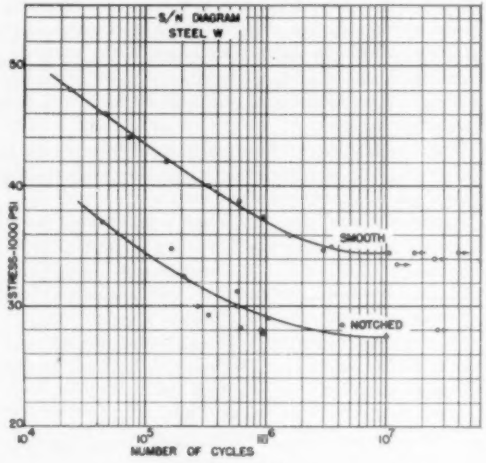

Figure 13

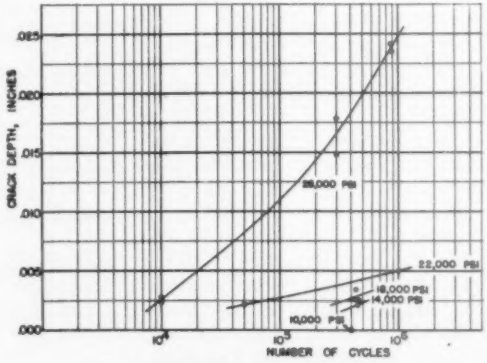

Fig. 14 Steel W, crack growth data

* It was thought unnecessary to discuss the lesser work on Steel W as all the W data available agree with that of Steel B.

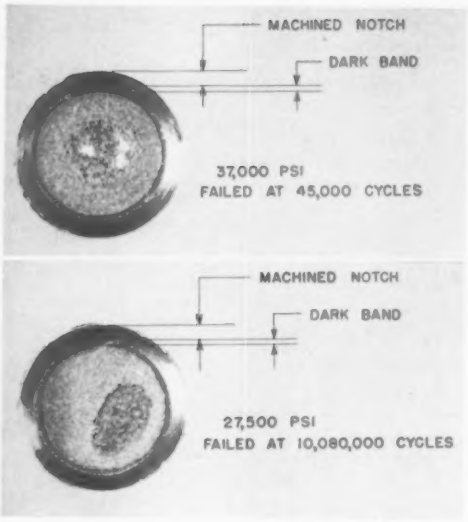

Fig. 15 Dark bands found in fatigue specimens of Steel W (the above specimens failed in fatigue)

One effect of the notch has been to make these specimens of a rather small test section since the behavior of the material at the root of the notch is the determining factor in these tests. Larger shifts and lower maximum energies of the transition curves might have resulted if the specimens had been prestressed or prestrained prior to notching.

The crack growth curve of Steel B (Fig. 11) presents some interesting new information. One observation is that fatigue cracks have formed at stresses well below the endurance limit. The lowest nominal stress at which a fatigue crack was found was 11,500 psi., about 45% of the endurance limit of the notched bars.

The fatigue cracks have grown with increasing numbers of cycles at all stresses investigated. As mentioned previously, the curvature and crossing of the lines of higher stress in Fig. 11 is thought to be due to the greater eccentricity of the specimens tolerated at that stage of the investigation.

The most revealing crack line is that for 21,500 psi. This stress had been chosen for investigation at high numbers of cycles because it was sufficiently far below the endurance limit, about 15%, to successfully avoid fracture due to scatter and yet high enough to experience positive effects from fatigue. One specimen was run to 83 million cycles at this stress, giving a point that shows the crack size at that stress to be steadily increasing.

It is interesting to observe that for the stresses below 23,200 psi., the crack lines indicate an approximately steady rate of growth, that is, the near parallelism of the lines indicates that the effect of variation of stress is more a variation of the point of crack occurrence and not a variation in their rate of propagation.

Reference is made to work done by H. F. Moore[4] on the propagation of fatigue cracks in railway car axles. Moore produced cracking by stressing above the endurance limits but propagated these cracks by stressing below the endurance limit. His work showed that the stress must be reduced to one half the endurance limit to avoid crack propagation. Although the present investigation is not exactly comparable it is interesting to note the agreement on about one half the conventional endurance limit as a form of "non-cracking endurance limit."

In their work on fatigue damage, Russell and Welcker[6] show damage regions for various materials, but these regions are above the endurance limit exclusively. Their criterion of damage was the inability of a specimen to run indefinitely at its original endurance limit.

The present report shows "damage" also below the endurance limit, although it is of a different nature. Nevertheless, this damage is very real. It appears that the effects of fatigue damage should be granted a wider range of investigation to determine the effect of fatigue on more of the physical properties of metals.

CONCLUSIONS

The present study has shown that several hitherto uninvestigated phenomena affect the characteristics of the transition curves.

It has been established that fatigue cracks develop and propagate at cyclic stresses below the endurance limit as well as above the endurance limit in both Steels B and W. Studies made of the behavior of their growth reveal a regular pattern of crack propagation extending outward to 83 million cycles at one stress level.

Cyclic prestressing in rotary bending, or static prestraining by tension, of specimens prior to the impact test, results in a shift of the original impact transition temperature curve toward regions of higher temperatures for Steel B.

When the fatigue prestressing is carried out at stress levels which result in crack formation, a large change in transition temperature, as well as a considerable reduction in maximum impact energy, occurs. On the other hand, prestressing at low stress levels which do not result in fatigue crack formation produces a smaller shift in the transition temperature with virtually no reduction in the maximum impact energy. Between these two limits lies the curve for specimens prestrained in static tension which indicates an intermediate transition temperature shift and an intermediate reduction in maximum impact energy.

While this investigation is obviously of an exploratory nature, it is, nevertheless, safe to conclude that the following phenomena, in their order of importance, produce a marked effect on the impact transition curves:

1. Fatigue damage accompanied by high stress concentrations associated with fatigue cracks.

2. Gross plastic deformations resulting probably in an increase of the micro (small scale) stress concentrations.
3. Fatigue damage which does not result in macro stress concentrations but which is undoubtedly associated with micro plastic deformations.

RECOMMENDATIONS

Stemming from the conclusions, the following recommendations for further investigation of the various phenomena noted above are indicated:

1. Effect of various amounts of plastic deformation (prestraining in tension) on the transition temperature. This work should include the study of notched impact specimens which have been machined out of prestrained material as well as the prestraining of originally notched specimens.

2. Effect of cyclic stress amplitude, both in direct (axial) loading as well as bending, on the rate of crack propagation.

3. The effect of cyclic stresses on the transition temperature at amplitudes below those which produce cracks. These should be carried out both in direct loading as well as bending.

From the viewpoint of fundamental investigation, such studies should be carried out on a variety of ferrous and nonferrous alloys regardless of their utility in ship construction. From a practical standpoint, ship plate materials which have been investigated in considerable detail by other research workers should be included in the program.

Consideration should also be given to the development of a technique whereby any physical changes in the plastic properties of the specimens during the process of static prestraining could be determined. Techniques such as those developed by Dr. B. J. Lazan[7] and those of Lessells and Associates, Inc.,[8] could very well be applied to the study of energy losses and changes in the elastic and plastic properties of the specimens during the cyclic prestressing operation.

ACKNOWLEDGMENT

The author wishes to thank the following for their invaluable aid during the course of the experimental work of this project: Joseph J. Connelly, Ralph E. Bowley, George R. Brown, Robert Zimmerman and the staff of Lessells and Associates, Inc., 916 Commonwealth Ave., Boston, Mass.

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Appendix A

CHARACTERISTICS OF STEELS B AND W

	Steel B	*Steel W*
	Composition	
C, %	0.18	0.21
Mn, %	0.73	0.52
P, %	0.011	0.013
S, %	0.030	0.010
Si, %	0.040	0.23
N, %	0.006	0.0049
	Mechanical Properties	
Tensile strength, psi.	59,600	62,540
Yield point, psi.	35,800	37,230
Elongation in 8 in., %	26.0	30.3

PREPARATION OF ROUND-NOTCHED SPECIMENS

Both Steel B and Steel W were received in $^3/_4$-in. plate form, hot-rolled, with some sheared and some flame cut edges. These plates were tested as-received with no additional heat treatment.

All the specimens were cut out with their length parallel to the direction of rolling and were taken from the middle of the thickness of the plate. Each specimen was marked so that the direction of the thickness of the original plate was perpendicular to the direction of the impact blow of the Charpy machine. Care was taken that no specimen test section was closer than 2 in. to a flame-cut edge.

Drawings of the impact and fatigue specimen are shown in Fig. 1. The impact specimen had to be cut away (milled) at *A* and *B* as shown to permit the broken halves to pass through the Charpy machine without jamming. However, an occasional jam was experienced.

The tapered ends and over-all length of the fatigue specimen correspond to the standard specimen used in the R. R. Moore rotating beam fatigue machine.

The notch was cut in a single operation using a tungsten carbide tool. A 10-in. South Bend tool room lathe was employed. The specimen was held in a collet and the back gears employed to give the slowest spindle speed of about 40 rpm. As the work was revolving in reverse, it was necessary to invert the cutting tool in the tool post. The smallest feed available, 0.002 in. per revolution, was used. Higher spindle speeds and feeds were tried but the notch finishes obtained were not so good as the low-speed finish. The work was constantly lubricated with carbon tetrachloride during notching. It was possible to hold the diameter of the specimen at the base of the notch to 0.400 plus 0.002 in. minus zero.

The tungsten carbide tool was first ground to a 45° angle and the tip radius was formed by hand honing with a 220-grit diamond hone. A Jones and Lamson optical comparator set for 62.5 × was used for measur-

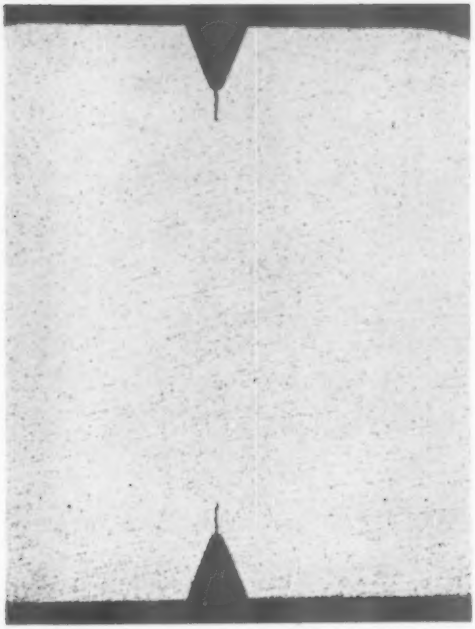

Fig. 16 Fatigue cracks in Steel B; 29,700 psi., 250,000 cycles

ing the tip radius and tool angle. In this manner it was possible to produce the 45° angle within one degree and the 0.005 in. radius on the tip within 0.0002 in. on the radius.

After experience had been gained in machining these notches, it was decided to regrind the tool bit and rehone the radius after every 40 notches. In this interval, the tool angle did not change appreciably but the tip radius would be reduced about 0.0002 in.

USE OF THE R. R. MOORE FATIGUE MACHINE

One of the R. R. Moore rotating beam fatigue machines used in this work is pictured in Fig. 3.

The specimen is held in tapered sleeves mounted in ball-bearing housings. Equal moments are applied to each housing to give a constant bending moment across the specimen. The moments are applied by a dead load to each housing through an equalizing bar.

The fiber stress experienced by a specimen in this machine is dependent on the diameter of the specimen and the dead load applied. Each specimen was measured to the nearest 0.0005 in. and the applied load for a given stress calculated.

It was noted that the eccentricity of specimens appeared to have an appreciable effect on the scatter of data in the fatigue tests. Eccentricity of the smooth specimens (standard R. R. Moore specimens, 0.300 in. diameter) usually resulted in scatter only, while eccentricity of the larger notched specimens would sometimes result in obviously premature fracture.

Quantitative standards of eccentricity were obtained in the following manner: With a specimen assembled in the fatigue machine, a dial indicator mounted on a heavy base was rested on the specimen turned by hand. In general, if the dial indicator showed a variation of more than 0.005 in. in reading, the specimen would vibrate severely and premature fracture or excessive scatter was expected. For best results, the eccentricity was kept below 0.002 in.

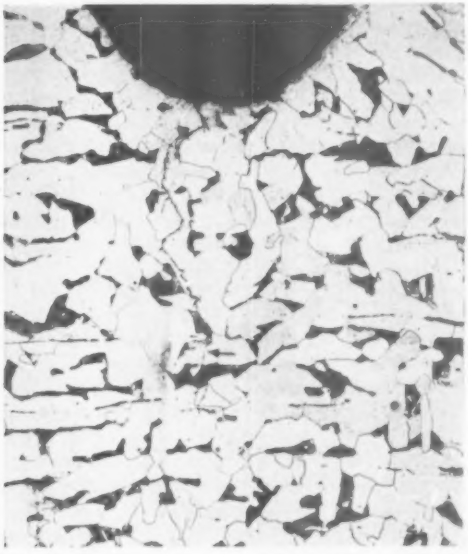

Fig. 17 Photomicrograph of Steel B (270 ×); showing crack after 100,000 cycles at 27,500 psi.

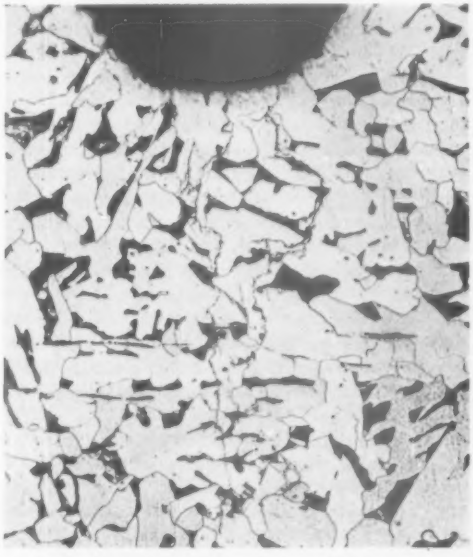

Fig. 18 Photomicrograph of Steel B (270 ×); showing crack after 200,000 cycles at 25,000 psi.

Fig. 19 Photomicrograph of Steel B (270 ×); showing crack after 200,000 cycles at 23,200 psi.

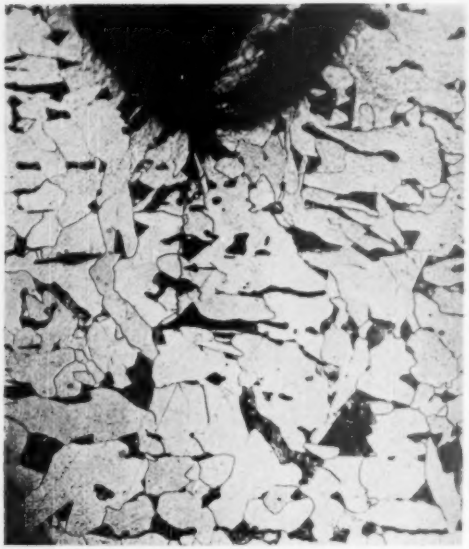

Fig. 20 Photomicrograph of Steel B (270 ×); showing crack after 80,000 cycles at 23,200 psi.

Test data in which this care had been taken are shown in the S/N diagrams of both steels and lines of crack growth for Steel B below 23,200 psi.

The scatter of data for the S/N diagram for notched specimens of Steel W is worthy of discussion. The initial fatigue tests on round-notched specimens of Steel W showed a great amount of scatter. Fractures were experienced at stresses 5000 psi. below stresses where some specimens had run 12 million cycles without fracture. Since the S/N diagram for standard smooth specimens showed little scatter, the notch finish was investigated.

The same notching method which produced a smooth finish in Steel B was found to leave small circumferential ridges at the root of the notch and occasionally would tear small particles out of the bottom of the notch.

Specimens with no tears were selected for further use, the others discarded. The minute ridges in the notch were lapped off by using No. 30 bare copper wire and 440-grit lapping compound. The specimen to be lapped was held in a lathe collet with the spindle revolving at about 100 rpm. The wire was rotated by means of an electric drill running at about 300 rpm. The other end of the wire was gripped in a pin vise mounted in a small ball bearing. The drill and ball bearing were held by hand and with a slight tension on the wire. The rotating wire was brought to bear on the bottom of the notch for 30 sec.

The notch finish obtained in this manner was not quite so good as that obtained in Steel B by machining alone. However, fatigue tests of lapped specimens gave usable data.

FATIGUE CRACK INVESTIGATION

When the dark bands on the fracture faces of the fatigue specimens were observed, it was attempted to prove that they represented fatigue cracks by means of nondestructive crack detection tests. Magnaflux, Zyglo and penetrating dyes were all used unsuccessfully.

Presumably the Magnaflux test failed because of the disturbing effect of the notch itself. The dyes would penetrate the crack but not in a quantity sufficient to produce discoloration at the bottom of the notch after cleaning.

A destructive method of sectioning, mounting and polishing was resorted to. This method was very successful and was used exclusively thereafter.

In this method, one end of the specimen was cut off about $^1/_2$ in. away from the notch. A longitudinal cut was then made along the length of the specimen to about $^1/_2$ in. on the other side of the notch. The cutting wheel was 0.030 in. thick. This cut was not centrally located but was sufficiently offset so that one portion of the specimen was truly a half specimen. This true half was then cut free of the remainder and mounted in a conventional bakelite base.

The specimen was polished and slightly etched. Some photographs of these sections are shown in Figs. 17–20.

Cracks were readily located in this manner and were plainly visible under a microscope down to a few ten thousandths of an inch in length.

The crack lengths, or actually, the depths of crack penetration, were measured by using the objective and lighting system of a Tukon tester with an eyepiece

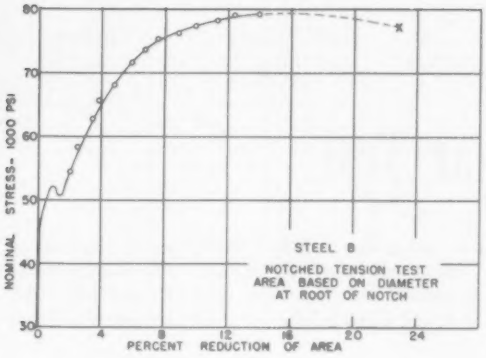

Figure 21

equipped with movable cross-hairs mounted on a calibrated micrometer lead screw.

In the plots of cracks growth data, it may be seen that there are either one or two points plotted for each stress and number of cycles. In both cases only one specimen was used. Originally only one side of a specimen was measured for crack penetration but later both sides were measured and plotted.

Of all these specimens there was found only one which had fatigue cracks large enough to be visible to the naked eye. This specimen was run at 29,700 psi. for 250,000 cycles. Since this number of cycles is past the point necessary to produce failure at that stress, it can be assumed that failure was imminent at this point. A photograph of the entire cross section of this specimen is shown in Fig. 16.

Austrian Steel Specification

THE Austrian Standards Committee in Vienna issued recently a specification M3115 on special steels for bridge and building construction. It is the first of the new Austrian materials specifications to consider weldability. "Yield point and weldability are essential requirements." Three steels are considered.

St37T (tensile strength = 52,500 to 64,000 psi.)
St44T (tensile strength = 62,500 to 74,000 psi.)
St52T (tensile strength = 74,000 to 91,000 psi.)

Minimum yield points and elongations are specified for plates 0.20 to 2.0 in. thick. The plunger radius for 180° bend also is specified for the as-rolled steels. In all three grades the carbon content must not exceed 0.20%, phosphorus and sulphur individually must not exceed 0.06% and their sum must not exceed 0.10%. For St52T silicon must not exceed 0.60%. If these limits are met and the weld-tensile and weld-bend tests (or bead-bend test) are passed, the steel is considered to have adequate weldability. The bead-bend test is required only for the following thicknesses:

St37T— Over 1.18 and up to 2.0 in.
St44T— Over 1.00 and up to 2.0 in.
St52T— Over 0.79 and up to 2.0 in.

All thicknesses of plates and wide flange sections of St52T must be normalized. Normalizing also is required for St44T over 1.0 in. thick and for St37T over 1.18 in. thick.

Both St37T and St44T (if the tensile strength of St44T does not exceed 71,000 psi.) are suitable for cold bending in the normalized condition if the following test can be passed. With the bending edge perpendicular to the direction of rolling a bend angle of 90° must be attained with a radius of 2A for St37T and 2.5A for St44T, where A = thickness. With the bending edge parallel to the direction of rolling the corresponding requirements for radius are 2.5A and 3A. Specification M3052 (Bead-Bend Test) has been issued, while the specifications M3050 and 3051 for weld-tensile and weld-bend tests are in preparation. Specification M315 is considered to apply to railway rolling stock and machine fabrication as well as to bridges. Copies can be obtained from Geschäftsstelle des Osterreichischen Normenausschusses, Metternichgasse 3, Vienna III, Austria.

Firecraker Welding for Stainless

A PATENTED covered electrode for welding stainless and heat-resisting steels by the firecracker process has been announced by Gebr. Böhler & Co., Vienna, Austria and Elin A.-G. The core rod contains about 0.10% C, 19.0% Cr, 9.0% Ni, 2.5% Mo and 0.8% Cb, and the electrode can be used for welding all stainless steels of the chromium and chromium-nickel types. The weld metal is stabilized and requires no heat treatment. The electrodes are furnished in $^{3}/_{32}$, $^{1}/_{8}$ and $^{5}/_{32}$ in. sizes, 41 in. long, although other lengths can be supplied. The coating thickness is such that the electrode lies on the copper backing bar of the firecracker welding jig with an air gap of 0.008–0.012 in. Straight polarity is required; alternating current cannot be used. The arc is struck with the aid of a carbon rod. Sheets 0.040 in. thick are welded with $^{3}/_{32}$-in. electrodes, 60–80 amp. Electrodes, $^{1}/_{8}$ in. are used for sheets 0.043–0.055 in. thick with 90–130 amp. The $^{5}/_{32}$-in. electrodes require 110–150 amp. for sheets 0.059–0.087 in. thick. Heavier sheets have not been studied. The welding speed is about 11 in. per minute. (Abstract of an article in *Schweisstechnik*, **3**, 97–99 (Sept. 1949)).

Further Study of Navy Tear Test

This paper presents further data on the application of the Navy tear-test method to the evaluation of notch-sensitivity characteristics of medium and high-tensile steel ship plate of current production

by Noah A. Kahn and Emil A. Imbembo

Abstract

In previous papers,[1, 2, 3] the authors described the Navy tear-test method for evaluating the susceptibility of steel plate to cleavage fracture and discussed data on the notch-sensitivity characteristics of a number of medium, high-tensile and high-yield alloy steels. Data on the correlation of the Navy tear test with the 72-in. wide plate tests on a number of the so-called project steels were also presented.

This paper presents further data on the application of the Navy tear-test method to the evaluation of notch-sensitivity characteristics of medium and high-tensile ship plate steels of current production and some special heats of medium steel, tested in plate thicknesses ranging from 1/2 to 1 1/2-in. The influence of type of steel (process and chemistry), plate thickness, stress-relieving and normalizing, and microstructure on the tear-test transition temperature is also discussed.

INTRODUCTION

IN PAPERS presented before the 1947 Annual Meeting of the AMERICAN WELDING SOCIETY[1] and the 1948 Annual Meeting of the American Society for Testing Materials, [2] the authors described a laboratory-scale test method for evaluating the susceptibility of steel plate to brittle or cleavage-type fracture. The Navy tear-test method, as it has been named, was shown to be capable of sharply defining the transition temperature range of ship plate and related structural steels using either the energy to propagate tearing or the percentage of shear in the fracture as the basis for evaluating the change from ductile to brittle-type fracture. The two bases of evaluation yielded the same temperature region of transition. The following advantages were cited for the test method:

(*a*) The material is tested in full plate thickness and the specimen includes a fracture area adequate for visual evaluation of the fracture type.

(*b*) It is economical in regard to material, time and cost of specimen preparation and testing, and utilizes a test specimen which is simple in design and readily reproducible.

(*c*) The transition temperature evaluation may be made by visual estimation of the percentage of shear in the fracture without the need for energy measurements.

The papers discussed the application of the tear test to a number of the so-called project steels and the data obtained indicated reasonably good correlation between tear test and 72-in. wide plate transition temperatures.

In a subsequent paper[3] read before the 1948 Annual Meeting of the AMERICAN WELDING SOCIETY, the authors presented data on the notch-sensitivity characteristics, as revealed by the Navy tear test, of a number of additional plate steels consisting of rimmed, semikilled and fully killed medium steels in 1/2 and 3/4 in. as-rolled thicknesses (yield strength 30,000–35,000 psi.), vanity-type high-tensile steels in as-rolled thicknesses of 7/8, 1 and 1 1/4 in. (yield strength, 50,000 psi. minimum) and special high-yield alloy steels in thicknesses of 3/4 and 1 in. (heat treated to a minimum yield strength of 75,000 psi.). The paper also discussed the effects of nitrogen content and some variations in specimen geometry and plate thickness and the applicability of the Navy tear test to quality control of ship plate and related structural steels. It was concluded that, until such time as we arrive at a broader understanding of notch-sensitivity and how it is influenced by specific variables in mill practice and chemistry of the steel, we must, by necessity, depend on an actual test performance to differentiate between steels with respect to their relative susceptibility to cleavage fracture.

PURPOSE

This paper presents further data on the application of the Navy tear-test method to the evaluation of notch-sensitivity characteristics of medium and high-tensile steel ship plate of current production. The broad objectives are to supplement our knowledge of the subject and provide a basis for improvement of ship plate specifications designed to discriminate against steels which would tend to fail in a brittle mode under ship service conditions.

SCOPE OF WORK

On the basis of action initiated by the Bureau of Ships of the Navy Department, sample plate materials taken from current production heats of medium and high-tensile steel were made available to the authors, through Naval inspection offices, for a study of notch-sensitivity characteristics by the tear-test method. These included semikilled medium steels with normal and higher manganese contents, fully killed medium steels, and vanity-type high-tensile steels. Data on a number of special heats of medium steel have been included because of their availability in more than one thickness from the same heat or because of having been produced under some variance from conventional mill practices.* Specifically, the paper presents data on 67 heats of medium steel covering plate thicknesses of 1/2, 5/8, 3/4, 1 and 1 1/2 in. and 27 heats of high-tensile steel covering plate thicknesses of 1/2, 5/8, 7/8, 1 and 1 1/4 in. In a number of instances, the effects of stress-relieving and normalizing treatments and the influence of microstructure were also studied.

METHOD

A discussion of results of preliminary work on the influence of geometrical

Noah A. Kahn and **Emil A. Imbembo** are Principal Metallurgist and Senior Metallurgist, respectively, Material Laboratory, New York Naval Shipyard, Brooklyn, N. Y.

Presented at the Thirtieth Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

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* Work on the special steels was conducted in collaboration with the Ship Structure Committee and coordinated by the National Research Council.

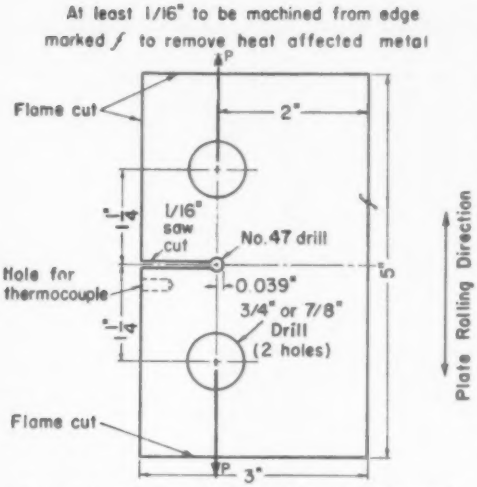

Fig. 1 Navy tear-test plate specimen keyhole-notch

Note: P-P indicates direction of load application

variables in the tear-test specimen was included in the previous papers.[1,2,3] This work is still in progress and will be reported at a later date. All findings presented in this paper are based on the use of the tear-test specimen previously used and shown in Fig. 1. Since the method of conducting the tear test has been described in considerable detail,[1,2] it need not be repeated herein.

An example of the manner in which the data are generally assembled for evaluation is illustrated by Fig. 2, which shows the tear-test characteristics of a 1 1/4-in. high-tensile steel plate in the as-rolled and normalized conditions. As previously indicated,[1,2,3] the maximum load and energy to start fracture are practically unaffected by the mode of fracture over the temperature range investigated. However, the energy to propagate fracture and the percentage of shear in the fracture are subject to a discontinuous and abrupt change over a temperature band which marks the transition from ductile, shear-type to brittle, cleavage-type fracture. The highest temperature at which first evidence of marked scatter in the per cent shear and energy-to-propagate values occurs is designated as the start of transition. By arbitrary definition, the start of transition based on fracture appearance is taken as the highest test temperature at which one or more specimens exhibit a shear area originating from the notch of less than 50% of the entire fracture area. Similarly, the start of transition based on energy evaluation is taken as the highest test temperature at which one or more specimens show an energy-to-propagate value of less than half of the energy level in the predominantly shear region. With a few exceptions, both methods of evaluation have indicated the same temperature at start of transition; in the few cases where they did not, the difference was only nominal and amounted to 10° F. or less. Further reference to transition temperature in this paper pertains to the temperature at start of transition as defined above. In connection with Fig. 2, attention is invited to a revised method of presenting results of tear tests in which the maximum load and energy quantities are expressed in trems of unit plate thickness in order to facilitate a qualitative comparison of data obtained on plates of various thicknesses. However, such treatment of the data can only be justified for the sake of comparison since the relationship of energy absorption to thickness is not a linear function and remains to be established.

EXPERIMENTAL RESULTS

Summaries of the tear-test data are given in Tables 1 to 5, inclusive, in which the chemical composition and static tensile properties, wherever available, are also listed. The so-called project steels have also been included in these tabulations and are designated by the project symbol letter in quotation marks; these are intended to aid in the evaluation of the tear-test data for current production materials in the light of the established correlation between the tear test and 72-in. wide plate tests. In a number of instances, a transition temperature has been indicated as being either less than or greater than a certain temperature. Most of these cases involved quality control samples; in order to expedite inspection of plates represented by the samples, triplicate tear tests were conducted at a single temperature, the results of which were used as the basis for final disposition of the

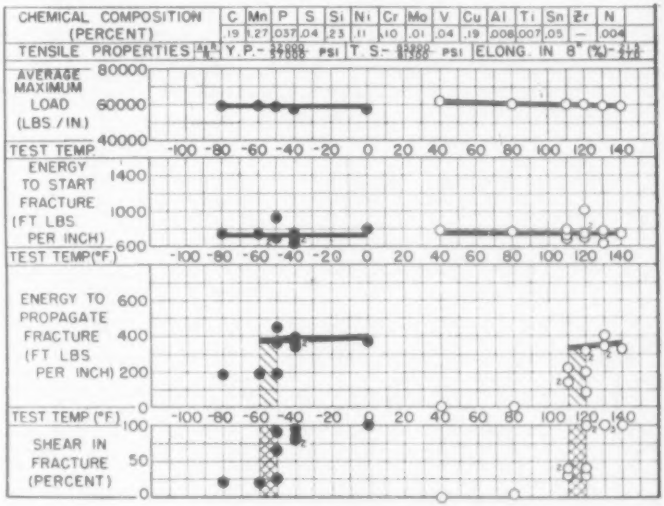
CHEMICAL COMPOSITION (PERCENT)
C .19 Mn 1.27 P .037 S .04 Si .23 Ni .11 Cr .10 Mo .01 V .04 Cu .19 Al .008 Ti .007 Sn .05 Zr — N .004
TENSILE PROPERTIES Y.P. 34000 51000 PSI T.S. 63300 81500 PSI ELONG. IN 8" (%) 21.5 27.0
AVERAGE MAXIMUM LOAD (LBS./IN.)
80000
60000
40000
TEST TEMP.
-100 -80 -60 -40 -20 0 20 40 60 80 100 120 140
ENERGY TO START FRACTURE (FT LBS PER INCH)
1400
1000
600
TEST TEMP(°F)
ENERGY TO PROPAGATE FRACTURE (FT LBS PER INCH)
600
400
200
0
TEST TEMP (°F)
SHEAR IN FRACTURE (PERCENT)
100
50
0
○ - As-Rolled ● - Normalized (Lab)

Fig. 2 Tear-test properties of high-tensile steel plate

Nominal thickness, 1 1/4 in. (51.0 lb.), Material Lab. code 16 × 7

Table 1—Composition, Tensile and Tear-Test Properties of Ship Plate Steels, Medium, Rimmed

Description				Composition, %					Static tensile properties			Tear test properties				
Heat code	Plate code	Plate thickness, in.	Condition	C	Mn	Si	Al	N	Yield point, psi.	Tensile strength, psi.	Elongation, % in 8 in.	Maximum load, Lb./in.*	Energy to start, ft.-lb./in.*	Energy to prop., ft.-lb./in.*	Transition Temps., °F.	Mn/C
1	"E"	1/2	R	0.19	0.35	0.01	0.003	0.003				49,000	1010	810	0	1.8
1	"E"	5/8	R	0.23	0.37	0.004	−0.002	0.004	30,950	58,430	30.6	65,400	870	680	140	1.8
2	Cy	3/4	R	0.18	0.34	0.01	...	0.004	37,340	61,440	26.0	67,900	890	660	100	1.9
3	Cz	3/4	R	0.16	0.40	0.01	...	0.004	35,550	57,310	30.0	68,200	1100	880	100	2.5
4	Cx	3/4	R	0.14	0.47	0.01	...	0.004	36,830	57,320	33.0	68,900	1210	850	80	3.4

* Average of all tests conducted above transition temperature.

Table 2—Composition, Tensile and Tear-Test Properties of Ship Plate Steels, Medium, Semikilled, 48-S-5, Normal Manganese (Mn/C<3)

Description				Composition, %					Static tensile properties			Tear-test properties				
Heat code	Plate code	Plate thickness, in.	Condition	C	Mn	Si	Al	N	Yield point, psi.	Tensile strength, psi.	Elongation, %, 8 in.	Maximum load, lb./in.*	Energy to start, ft.-lb./in.*	Energy to prop., ft.-lb./in.*	Transition temp., ° F.	Mn/C
5	G2	1/2	R	0.25	0.42	0.08	0.003	0.004	...	...	...	56,000	1140	750	50	1.7
5	G3	3/4	R	0.25	0.42	0.08	0.003	0.004	...	...	...	52,600	1060	860	100	1.7
5	G4	1	R	0.24	0.42	0.08	0.003	0.004	...	...	...	50,900	1320	980	120	1.7
6	"A"	3/4	R	0.25	0.49	0.04	0.004	0.004	34,090	58,640	33.4	48,300	930	640	70	2.0
7	"C"	3/4	R	0.25	0.51	0.05	0.015	0.009	35,500	65,240	30.4	51,800	880	610	135	2.0
8	S7	3/4	R	0.21	0.49	0.08	0.002	0.005	35,800	63,200	35.5	48,000	800	730	120	2.3
9	S6	3/4	R	0.20	0.55	0.10	−0.002	0.005	34,900	66,000	30.0	53,800	1060	880	100	2.8
10	S9	3/4	R	0.18	0.50	0.07	−0.002	0.004	32,600	57,900	34.5	53,000	1550	1000	80	2.8
11	S10	3/4	R	0.19	0.54	0.12	−0.006	0.004	33,300	61,400	31.0	56,000	1190	960	90	2.8
12	S11	3/4	R	0.20	0.55	0.06	−0.006	0.004	31,300	59,400	31.0	49,200	910	760	90	2.8
13	S8	3/4	R	0.14	0.46	0.07	−0.002	0.005	32,300	57,400	32.0	46,400	950	780	90	2.9

* Average of all tests conducted above transition temperature.

material. For purposes of comparison, the maximum load and energy values given in the tables are based on averages of all tests made above the transition temperature. A detailed description of the tabular data is given below:

(*a*) Table 1 covers data on 4 heats of rimmed medium steel plate, as-rolled, in thicknesses of 1/2 and 3/4 in. which were reported in previous papers but are included herein for comparison with other steels.

(*b*) Table 2 covers 9 heats of semikilled medium steel plate, as-rolled, in thicknesses of 1/2, 3/4 and 1 in., with normal manganese content (Mn/C ratio less than 3) of the type represented by Grade M under Navy Dept. Specification 48-S-5. The G2-3-4 samples (Heat Code 5) were taken from plates of three thicknesses of the same heat which were used in structural assemblies produced for the purpose of evaluating certain ship structural design variables under investigation at the National Bureau of Standards. The S-Series steels appearing in this tabulation and also in Table 3 represent material which is being subjected to 12-in. internally notched wide plate tests at Swarthmore College and the David Taylor Model Basin.

(*c*) Table 3 covers 34 heats of semikilled medium steel plate in thicknesses of 1/2, 5/8, 3/4, 1 and 1 1/2 in. of the ABS, Class B type, manganese 0.60 to 0.90% (Mn/C ratio greater than 3). All heats were tested in the as-rolled condition and some in the normalized condition as well. The normalizing treatment, which was performed by the authors, was applied to the full plate thickness material, and consisted of heating to 1650° F., holding 1 hr. per inch of plate thickness, followed by cooling in still air. Attention is invited to the fact that a number of the plates in the S-series represent material produced under some variance from conventional mill practices in that the ingots, from which these plates were rolled, were treated with aluminum in the mold for finer grain. In this respect, these plates would probably be more representative of fully killed practice but have been included in the semikilled category in order to permit comparison with plates from companion ingots from the same heat which were not so treated. The M-series steels appearing in this tabulation and also in Table 4 represent quality control samples of material ordered for hull construction of a Naval vessel. The G5-6-7-8 samples (Heat Code 15) were taken from plates of 4 thicknesses of the same heat which are being used by Swarthmore College in an investigation of the geometry of internally-notched wide plate specimens, involving variations in the aspect ratio (ratio

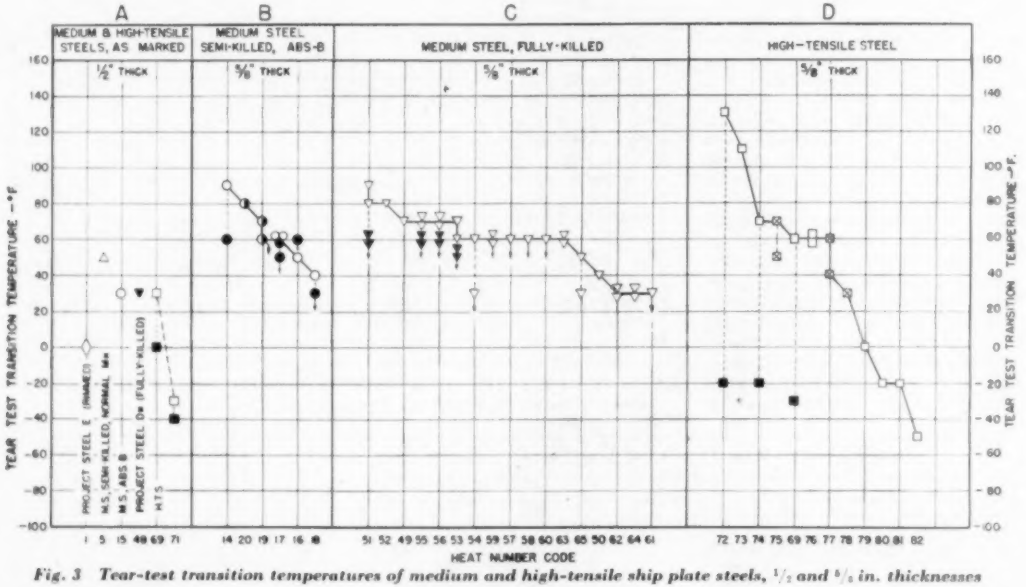

Fig. 3 Tear-test transition temperatures of medium and high-tensile ship plate steels, 1/2 and 5/8 in. thicknesses

Solid points—normalized; x, shown in a square in illustration—stress relieved; all others, as-rolled

of specimen width to plate thickness).

(*d*) Table 4 covers 20 heats of fully killed medium steel plate in thicknesses of 1/2, 5/8 and 3/4 in. All heats with the exception of Code 67 (Project Steel "H") were silicon-killed while "H" was aluminum-killed. All heats were tested in the as-rolled condition and some in the normalized condition as well. With the exception of project steel "Dn," all normalized plates were heat-treated by the authors, following the procedure indicated above. A portion of heat code 66 (Steel W) has been investigated by Swarthmore College for behavior under wide plate tests.

(*e*) Table 5 covers 27 heats of high-tensile steel plate (fully killed) in thicknesses of 1/2, 5/8, 7/8, 1 and 1 1/4 in. of the so-called vanity type (vanadium and titanium treated) covered by Grade HT under Navy Dept. Specification 48-S-5. All plates represent quality control samples of material ordered for hull construction of Naval vessels. The normalized plates were treated by the authors using the same normalizing treatment as applied to medium steel. The plates represented by heats 75, 77 and 78 were stress-relieved at the mill after rolling and straightening (1150° F., air cooled) with a view of improving ductility in order to meet the minimum elongation requirement of the specification. Heats 68 and 70 were simi-

Table 3—Composition, Tensile and Tear-Test Properties of Ship Plate Steels, Medium, Semikilled, ABS-B, Manganese 0.60/0.90 (Mn/C>3)

Description				Composition, %					Static tensile properties			Tear-test Properties				
Heat code	Plate code	Plate thick., in.	Condition	C	Mn	Si	Al	N	Y. P. (P.S.I.)	T. S. (P.S.I.)	Elong. % in 8"	Max. load,* lbs./in.	Energy to start,* ft. lbs./in.	Energy to prop.,* ft. lbs./in.	Transition temp., °F.	Mn/C
14	M29B	5/8	R	0.22	0.90	0.03	0.004	0.006	40,180	68,030	27.5	55,700	1110	870	90	4.1
14	M29B	5/8	N	0.22	0.90	0.03	0.004	0.006	...	...	...	56,900	1210	780	60	4.1
14	M29A	1	R	0.22	0.90	0.03	0.008	0.004	38,830	63,820	31.7	57,100	1530	1100	120	4.1
14	M29A	1	N	0.22	0.90	0.03	0.008	0.004	...	...	...	...	...	...	>70	4.1
15	G5	1/2	R	0.18	0.96	0.05	0.006	0.004	...	...	...	57,100	1450	940	30	5.3
15	G6	5/8	R	0.18	0.96	0.05	0.005	0.003	...	...	...	56,900	1690	1040	50	5.3
15	G7	1	R	0.18	0.96	0.04	0.006	0.003	...	...	...	57,600	1970	1150	80	5.3
15	G8	1 1/2	R	0.18	0.96	0.04	0.007	0.003	...	...	...	59,100	2410	1150	130	5.3
16	M37	5/8	R	0.20	0.74	0.07	0.008	0.004	...	...	...	53,800	1290	740	50	3.7
16	M37	5/8	N	0.20	0.74	0.07	0.008	0.004	...	...	...	53,100	1290	900	<70	3.7
17-1	M38A	5/8	R	0.19	0.72	0.08	0.005	0.005	...	...	...	53,100	1310	880	60	3.8
17-1	M38A	5/8	N	0.19	0.72	0.08	0.005	0.005	...	...	...	53,600	1320	890	60	3.8
17-2	M38B	5/8	R	0.19	0.72	0.08	0.005	0.005	...	...	...	52,900	1260	770	60	3.8
17-2	M38B	5/8	N	0.19	0.72	0.08	0.005	0.005	...	...	...	54,000	1460	880	<60	3.8
18	M39	5/8	R	0.21	0.82	0.05	0.005	0.004	35,540	63,400	31.7	54,600	1320	950	40	3.9
18	M39	5/8	N	0.21	0.82	0.05	0.005	0.004	...	...	...	55,100	1420	980	<40	3.9
19-1	M34A	5/8	R	0.22	0.89	0.07	0.009	0.005	40,100	65,560	30.2	53,500	1090	770	60	4.0
19-1	M34A	5/8	N	0.22	0.89	0.07	0.009	0.005	...	...	...	54,800	1130	850	70	4.0
19-2	M34B	5/8	R	0.22	0.89	0.07	0.006	0.004	...	...	...	54,100	1140	800	70	4.0
19-2	M34B	5/8	N	0.22	0.89	0.07	0.006	0.004	...	...	...	52,400	1180	830	<70	4.0
20	M30	5/8	R	0.22	0.90	0.03	0.006	0.006	39,900	70,470	28.0	57,000	1140	780	80	4.1
20	M30	5/8	N	0.22	0.90	0.03	0.006	0.006	...	...	...	57,500	1190	850	80	4.1
21	82	5/8	R	0.17	0.60	0.07	−0.003	0.005	31,370	57,970	32.8	52,900	1400	1050	110	3.5
21	83**	5/8	R	0.17	0.60	0.07	0.028	0.005	31,660	58,000	31.8	53,000	1350	1010	80	3.5
22	821	5/8	R	0.22	0.81	0.08	−0.006	0.004	37,900	68,300	26.0	56,200	1190	960	70	3.7
22	814**	5/8	R	0.22	0.81	0.07	0.04	0.004	36,700	66,400	31.0	56,900	1140	950	60	3.7
23	823	5/8	R	0.20	0.75	0.05	−0.006	0.005	34,200	66,200	30.0	53,000	1030	920	100	3.8
23	815**	5/8	R	0.20	0.75	0.06	0.05	0.004	34,000	62,600	31.0	53,400	1050	810	30	3.8
24	81	5/8	R	0.17	0.66	0.08	−0.003	0.005	31,780	58,720	32.4	51,500	1170	1000	100	3.9
25	813	5/8	R	0.17	0.68	0.07	−0.005	0.004	34,200	60,200	33.5	53,500	1360	1050	90	4.0
25	817**	5/8	R	0.17	0.68	0.07	0.04	0.004	34,100	60,600	33.0	51,500	1260	940	40	4.0
26	822	5/8	R	0.19	0.77	0.09	−0.006	0.004	35,000	63,800	32.0	59,900	1420	1010	100	4.1
26	812**	5/8	R	0.19	0.77	0.07	0.04	0.004	34,700	64,100	28.0	57,200	1230	880	40	4.1
27	820	5/8	R	0.18	0.73	0.07	−0.006	0.004	34,500	62,100	33.0	53,900	1220	990	80	4.1
27	816**	5/8	R	0.18	0.73	0.08	0.03	0.004	36,600	62,000	33.5	53,600	1210	920	50	4.1
28	819	5/8	R	0.19	0.78	0.09	−0.006	0.005	35,300	64,900	32.0	55,100	1190	1020	80	4.1
29	818	5/8	R	0.17	0.73	0.05	−0.006	0.005	33,500	62,100	32.0	52,100	1220	970	100	4.3
30	"B"	5/8	R	0.16	0.76	0.05	0.001	0.005	32,750	56,700	33.5	52,700	1430	840	60	4.7
31	85	5/8	R	0.17	0.90	0.09	−0.005	0.005	36,600	56,000	29.5	54,300	1090	1030	70	5.3
31	84**	5/8	R	0.17	0.90	0.10	0.04	0.004	36,250	65,100	30.8	56,600	1080	770	−20	5.3
32-1	M23A	1	R	0.33	0.76	0.08	0.005	0.006	37,150	67,120	29.7	55,300	1280	840	120	3.3
32-1	M23A	1	N	0.33	0.76	0.08	0.005	0.006	38,700	65,200	49.0(2")	55,200	1370	870	110	3.3
32-2	M23B	1	R	0.33	0.76	0.08	0.005	0.005	38,410	66,800	30.2	52,600	1220	920	130	3.3
32-2	M23B	1	N	0.33	0.76	0.08	0.005	0.005	...	...	...	53,500	1380	960	70	3.3
33-1	M22A	1	R	0.22	0.76	0.06	0.007	0.005	...	...	...	54,300	1390	890	120	3.4
33-1	M22A	1	N	0.22	0.76	0.06	0.007	0.005	...	...	...	53,800	1460	1040	90	3.4
33-2	M22B	1	R	0.22	0.76	0.06	0.014	0.004	...	...	...	53,200	1490	1060	130	3.4
33-2	M22B	1	N	0.22	0.76	0.06	0.014	0.004	...	...	...	54,600	1700	1070	80	3.4
34	M28	1	R	0.22	0.74	0.19	0.025	0.005	39,410	67,620	31.5	55,200	1350	830	70	3.4
34	M28	1	N	0.22	0.74	0.19	0.025	0.005	...	...	...	55,700	1550	900	<50	3.4
35-1	M18A	1	R	0.19	0.69	0.06	0.009	0.004	...	...	...	52,000	1240	930	120	3.5
35-1	M18A	1	N	0.19	0.69	0.06	0.009	0.004	...	...	...	51,700	1290	900	<70	3.5
35-2	M18B	1	R	0.19	0.69	0.05	0.014	0.003	38,560	64,020	27.5	50,900	1490	910	100	3.5
35-2	M18B	1	N	0.19	0.69	0.06	0.014	0.003	...	...	...	50,200	1410	910	70	3.5
36-1	M21A	1	R	0.24	0.76	0.07	0.007	0.004	36,580	66,780	30.5	54,300	1260	720	110	3.5
36-1	M21A	1	N	0.24	0.76	0.07	0.007	0.004	...	...	...	54,700	1470	880	70	3.5
36-2	M21B	1	R	0.24	0.76	0.07	0.012	0.004	...	...	...	54,700	1450	950	120	3.5
36-2	M21B	1	N	0.24	0.76	0.07	0.012	0.004	...	...	...	54,400	1420	900	60	3.5
37	M32	1	R	0.21	0.76	0.03	0.009	0.004	38,110	64,420	30.2	53,700	1400	960	110	3.6
37	M32	1	N	0.21	0.76	0.03	0.009	0.004	...	...	...	51,500	1400	940	70	3.6
38-1	M19A	1	R	0.24	0.87	0.07	0.006	0.004	...	...	...	55,300	1360	890	120	3.7
38-1	M19A	1	N	0.24	0.87	0.07	0.005	0.004	...	...	...	...	...	...	>100	3.7
38-2	M19B	1	R	0.24	0.87	0.07	0.007	0.004	...	...	...	52,900	1270	990	110	3.7
38-2	M19B	1	N	0.24	0.87	0.07	0.007	0.004	...	...	...	51,900	1330	940	60	3.7
39	M36	1	R	0.19	0.70	0.04	0.017	0.003	40,140	65,800	30.0	53,700	1590	980	110	3.7
39	M36	1	N	0.19	0.70	0.04	0.017	0.006	...	...	...	52,900	1570	1010	60	3.7
40-1	M24A	1	R	0.20	0.75	0.09	0.005	0.004	...	...	...	50,000	1060	770	50	3.8
40-1	M24A	1	N	0.20	0.75	0.09	0.005	0.004	...	...	...	50,900	1240	820	40	3.8
40-2	M24B	1	R	0.20	0.75	0.09	0.012	0.004	...	...	...	54,100	1130	900	140	3.8
40-2	M24B	1	N	0.20	0.75	0.09	0.012	0.004	...	...	...	54,300	1400	920	90	3.8
41	M26	1	R	0.19	0.72	0.09	0.016	0.005	...	...	...	54,200	1510	920	100	3.8
41	M26	1	N	0.19	0.72	0.09	0.016	0.005	...	...	...	53,800	1550	1020	<70	3.8
42-1	M25A	1	R	0.19	0.75	0.08	0.012	0.005	...	...	...	49,800	1400	730	100	3.9
42-1	M25A	1	N	0.19	0.75	0.08	0.012	0.005	...	...	...	51,200	1440	940	60	3.9
42-2	M25B	1	R	0.19	0.75	0.08	0.009	0.005	...	...	...	53,100	1340	860	100	3.9
42-2	M25B	1	N	0.19	0.75	0.08	0.009	0.005	...	...	...	...	...	...	>80	3.9
43	M27	1	R	0.21	0.81	0.07	0.021	0.006	38,650	63,820	33.5	52,600	1420	1010	100	3.9
43	M27	1	N	0.21	0.81	0.07	0.021	0.005	...	...	...	51,300	1340	980	70	3.9
44	M35	1	R	0.18	0.71	0.02	0.004	0.005	33,380	62,120	32.7	54,000	1530	970	140	3.9
44	M35	1	N	0.18	0.71	0.02	0.004	0.005	...	...	...	52,900	1670	1010	100	3.9
45	M31	1	R	0.21	0.86	0.08	0.007	0.005	38,390	67,520	30.5	57,000	1570	1090	120	4.1
45	M31	1	N	0.21	0.86	0.08	0.007	0.005	...	...	...	54,300	1560	1000	70	4.1
46-1	M20A	1	R	0.21	0.79	0.06	0.007	0.005	38,260	65,710	28.0	54,600	1420	930	100	4.2
46-1	M20A	1	N	0.21	0.79	0.06	0.007	0.005	...	...	...	53,400	1420	1020	80	4.2
46-2	M20B	1	R	0.21	0.79	0.06	0.007	0.007	37,160	66,130	31.0	55,600	1470	730	90	4.2
46-2	M20B	1	N	0.21	0.79	0.06	0.007	0.007	...	...	...	55,400	1490	1040	80	4.2
47	M33	1	R	0.21	0.90	0.08	0.006	0.005	...	...	...	55,300	1610	960	100	4.3
47	M33	1	N	0.21	0.90	0.08	0.006	0.005	...	...	...	55,200	1640	940	60	4.3

* Average of all tests conducted above transition temperature.
** Aluminum-treated.

Table 4—Composition, Tensile and Tear-Test Properties of Ship Plate Steels, Medium, Fully Killed (Si or Al)

Description				Composition, %					Static tensile properties			Tear-test properties				
Heat code	Plate code	Plate thickness, in.	Condition	C	Mn	Si	Al	N	Yield point, psi.	Tensile strength, psi.	Elongation, %, 8 in.	Maximum load, lb./in.*	Energy to start, ft.-lb./in.*	Energy to prop., ft.-lb./in.*	Transition temp., °F.	Mn/C
48	"Da"	1/2	N	0.20	0.55	0.23	0.022	0.003	...	...	...	52,700	1230	930	30	3.0
48	"Db"	3/4	R	0.19	0.55	0.25	0.015	0.005	37,600	65,060	30.3	55,800	1170	750	60	3.0
48	"Da"	3/4	N	0.20	0.55	0.23	0.02	0.005	34,700	59,550	31.9	54,700	1270	840	70	3.0
49	M2	3/4	R	0.26	0.38	0.23	−0.006	0.004	...	...	...	53,800	935	455	70	1.4
50	M1	3/4	R	0.22	0.38	0.26	−0.006	0.004	...	...	...	52,300	1000	675	40	1.7
51-1	M4A	3/4	R	0.23	0.40	0.19	...	0.004	...	...	...	54,600	1170	710	80	1.7
51-1	M4A	3/4	N	0.23	0.40	0.19	...	0.004	...	...	...	56,600	1240	790	<70	1.7
51-2	M4B	3/4	R	0.23	0.40	0.19	...	0.004	...	...	...	54,000	1070	780	90	1.7
51-2	M4B	3/4	N	0.23	0.40	0.19	...	0.004	...	...	...	58,300	1420	820	<70	1.7
52	M3	3/4	R	0.24	0.44	0.19	−0.006	0.005	...	...	...	52,100	835	655	80	1.9
53-1	M6A	3/4	R	0.23	0.43	0.19	...	0.003	...	...	...	53,700	975	735	70	1.9
53-1	M6A	3/4	N	0.23	0.43	0.19	...	0.003	...	...	...	56,500	1280	720	<70	1.9
53-2	M6B	3/4	R	0.23	0.43	0.19	...	0.003	...	...	...	54,100	1030	735	60	1.9
53-2	M6B	3/4	N	0.23	0.43	0.19	...	0.003	...	...	...	53,700	1140	740	<60	1.9
54-1	M12A	3/4	R	0.26	0.46	0.21	...	0.005	...	...	...	53,800	1060	740	60	1.9
54-2	M12B	3/4	R	0.26	0.46	0.21	...	0.005	...	...	...	51,800	885	670	<40	1.9
55-1	M17A	3/4	R	0.25	0.47	0.21	0.004	0.004	...	...	...	55,700	1000	740	70	1.9
55-1	M17A	3/4	N	0.25	0.47	0.21	0.004	0.004	...	...	...	55,700	1140	830	<70	1.9
55-2	M17B	3/4	R	0.25	0.47	0.22	...	0.005	...	...	...	55,000	1040	750	70	1.9
55-2	M17B	3/4	N	0.25	0.47	0.22	...	0.005	...	...	...	57,000	1190	800	<70	1.9
56-1	M5A	3/4	R	0.24	0.47	0.20	...	0.005	...	...	...	56,200	1025	745	70	2.0
56-1	M5A	3/4	N	0.24	0.47	0.20	...	0.005	...	...	...	59,500	1310	700	<70	2.0
56-2	M5B	3/4	R	0.24	0.47	0.20	...	0.005	...	...	...	55,000	985	720	70	2.0
56-2	M5B	3/4	N	0.24	0.47	0.20	...	0.005	...	...	...	56,700	1200	770	<70	2.0
57	M13	3/4	R	0.22	0.47	0.24	...	0.004	...	...	...	56,000	1200	760	<70	2.1
58	M16	3/4	R	0.24	0.52	0.22	...	0.005	...	...	...	54,200	1170	790	<70	2.2
59-1	M11A	3/4	R	0.21	0.49	0.22	...	0.005	...	...	...	53,400	1065	740	<70	2.3
59-2	M11B	3/4	R	0.21	0.49	0.22	...	0.005	...	...	...	54,500	1110	740	50	2.3
60	M14	3/4	R	0.19	0.44	0.20	...	0.005	...	...	...	52,500	1100	750	<70	2.3
61	M15	3/4	R	0.20	0.47	0.22	...	0.005	...	...	...	53,100	1240	860	<40	2.3
62-1	M10A	3/4	R	0.19	0.48	0.23	...	0.005	...	...	...	53,300	1030	720	30	2.5
62-2	M10B	3/4	R	0.19	0.48	0.23	...	0.005	...	...	...	53,400	1065	740	30	2.5
63-1	M7A	3/4	R	0.17	0.48	0.21	...	0.004	...	...	...	53,000	1230	840	50	2.8
63-2	M7B	3/4	R	0.17	0.48	0.21	...	0.004	...	...	...	52,400	1220	870	50	2.8
64-1	M9A	3/4	R	0.19	0.63	0.23	...	0.005	...	...	...	55,200	1170	795	30	3.3
64-2	M9B	3/4	R	0.19	0.63	0.23	...	0.005	...	...	...	54,600	1175	810	30	3.3
65-1	M8A	3/4	R	0.19	0.51	0.24	...	0.005	...	...	...	53,600	1040	700	30	3.7
65-2	M8B	3/4	R	0.19	0.51	0.24	...	0.005	...	...	...	53,500	1110	755	50	3.7
66	W	3/4	R	0.21	0.52	0.23	0.006	0.005	37,230	62,540	30.3	55,400	1320	870	60	2.6
67	"H"	3/4	R	0.17	0.78	0.16	0.037	0.005	35,000	62,550	29.8	55,000	1330	810	50	4.5

* Average of all tests conducted above transition temperature.

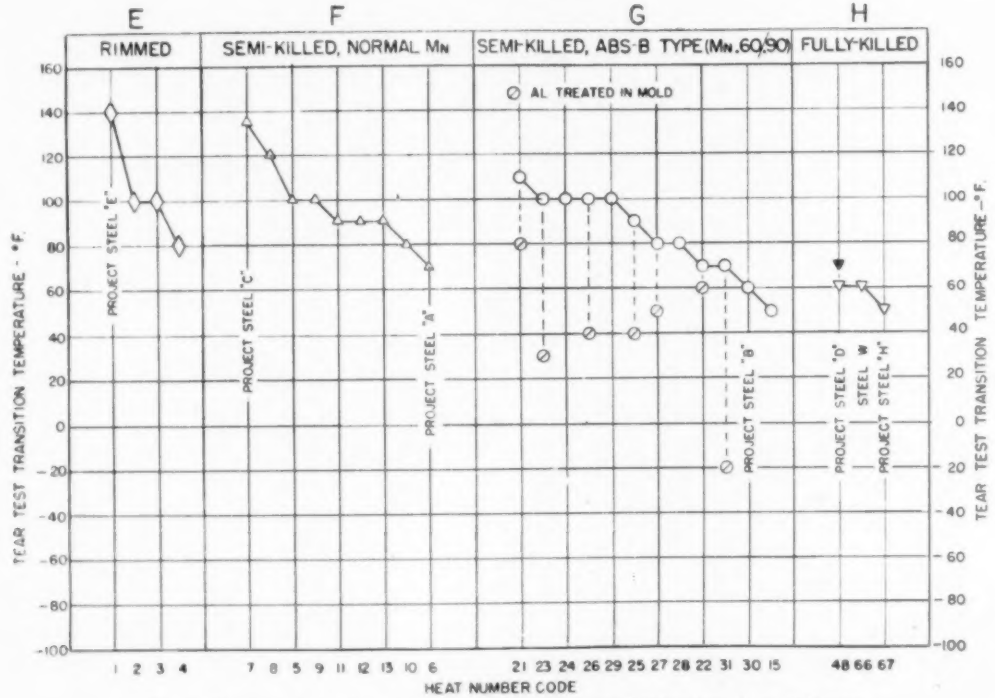

Fig. 4 Tear-test transition temperatures of medium steel ship plate, 3/4 in. thickness

Solid points—normalized; all others, as-rolled

Table 5—Composition, Tensile and Tear-Test Properties of Ship Plate Steels, High-Tensile, Vanity-Type, 48-S-5

Description				Composition, %					Static tensile properties			Tear-test properties				
Heat code	Plate code	Plate thickness, in.	Condition	C	Mn	Si	V	Ti	Yield point, psi.	Tensile strength, psi.	Elongation, %	Maximum load, lb./in.*	Energy to start, ft.-lb./in.*	Energy to prop., ft.-lb./in.*	Transition temp., ° F.	Mn/C
68	1X4	7/8	R	0.18	1.23	0.30	0.05	0.010	60,100	85,300	20.0	67,200	975	610	50	6.8
68	2X5	1	R	0.18	1.23	0.31	0.05	0.009	55,300	81,200	22.0	63,000	965	500	40	6.8
68-1	3X7	1 1/4	R	0.18	1.23	0.35	0.05	0.011	51,400	79,100	24.3	62,200	875	385	70	6.8
68-1	3X7	1 1/4	SR	0.18	1.23	0.35	0.05	0.011	....	....	....	60,700	790	350	80	6.8
68-2	4X7	1 1/4	R	0.18	1.23	0.31	0.05	0.012	50,200	79,000	24.3	61,300	860	390	60	6.8
68-2	4X7	1 1/4	N	0.18	1.23	0.31	0.05	0.012	55,000	77,400	29.0	59,500	940	460	−70	6.8
69	2Z1	1/2	R	0.15	1.15	0.25	0.05	0.034	56,000	79,740	24.7	69,100	1180	850	30	7.7
69	2Z1	1/2	N	0.15	1.15	0.25	0.05	0.034	....	....	....	65,400	1630	1080	0	7.7
69	1Z2	5/8	R	0.15	1.15	0.25	0.05	0.034	55,050	79,360	26.0	68,600	1190	950	60	7.7
69	1Z2	5/8	N	0.15	1.15	0.25	0.05	0.034	....	....	....	64,500	1590	1300	−30	7.7
70	21X4	7/8	R	0.15	1.25	0.25	0.04	0.007	57,200	78,500	26.0	62,500	880	725	40	8.3
70-1	19X7	1 1/4	R	0.15	1.25	0.24	0.04	0.007	55,000	78,900	25.3	61,200	905	500	100	8.3
70-1	19X7	1 1/4	SR	0.15	1.25	0.24	0.04	0.007	....	....	....	....	....	....	>80	8.3
70-2	18X7	1 1/4	R	0.15	1.25	0.23	0.04	0.007	53,200	73,800	26.8	59,600	905	500	20	8.3
70-2	18X7	1 1/4	SR	0.15	1.25	0.23	0.04	0.007	....	....	....	58,300	830	420	20	8.3
71	3Z1	1/2	R	0.16	0.98	0.18	0.04	0.025	49,750	70,430	27.0	60,300	1220	950	−30	6.1
71	3Z1	1/2	N	0.16	0.98	0.18	0.04	0.025	....	....	....	57,200	1190	930	−40	6.1
72	4Y2	5/8	R	....	....	....	....	....	55,000	78,000	23.0	71,600	1330	970	130	....
72	4Y2	5/8	N	....	....	....	....	....	53,700	71,600	27.0	69,700	1870	1050	−20	....
73	5Y2	5/8	R	0.15	1.19	0.33	0.04	0.009	56,800	79,200	24.0	68,400	1180	980	110	8.5
74	1Y2	5/8	R	0.15	1.15	0.30	0.04	0.009	50,800	72,700	44.0†	64,500	1060	960	70	7.7
74	1Y2	5/8	N	0.15	1.15	0.30	0.04	0.009	51,000	73,000	49.5†	64,000	1440	820	−20	7.7
75-1	23X2	5/8	SR	0.16	1.22	0.25	0.078	0.007	59,600	77,200	43.0†	65,300	1000	940	70	7.6
75-2	26X2	5/8	SR	0.16	1.22	0.25	0.078	0.007	58,600	76,000	42.0†	66,100	950	870	50	7.6
76-1	6Y2A	5/8	R	0.14	1.00	0.24	0.04	0.024	48,800	70,000	47.5†	66,100	1550	940	60	7.2
76-2	6Y2B	5/8	R	0.14	1.00	0.26	0.04	0.011	49,100	70,900	46.5†	66,800	1420	820	60	7.2
77-1	23X2	5/8	SR	0.16	1.30	0.26	0.072	0.007	53,400	74,800	48.0†	66,900	1050	890	60	8.1
77-2	27X2	5/8	SR	0.16	1.30	0.26	0.072	0.007	56,700	76,600	45.0†	66,000	1050	900	40	8.1
78	24X2	5/8	SR	0.15	1.25	0.25	0.064	0.008	59,200	77,700	42.0†	67,800	1110	770	30	8.3
79	29X2	5/8	R	0.13	1.16	0.24	0.032	0.007	57,500	82,300	18.3	63,900	600	370	<0	8.9
80	30X2	5/8	R	0.14	1.20	0.25	0.07	0.006	59,600	83,400	18.5	62,000	670	290	−20	8.6
81	31X2	5/8	R	0.14	1.21	0.26	0.07	0.007	58,800	83,200	22.5	63,600	600	340	−20	8.6
82	28X2	5/8	R	0.16	1.02	0.27	0.064	0.008	54,200	77,000	25.0	62,700	770	580	−50	6.4
83	2Y5	1	R	0.20	1.07	0.27	0.04	0.005	50,000	76,200	23.0	62,300	1170	740	70	5.4
83	2Y5	1	N	0.20	1.07	0.27	0.04	0.006	53,700	75,600	28.0	58,100	1060	780	−40	5.4
84	3Y5	1	R	0.19	1.18	0.33	0.05	0.005	52,200	77,800	24.0	70,900	1360	720	60	6.2
84	3Y5	1	N	0.19	1.18	0.33	0.05	0.005	....	....	....	67,800	1340	1020	0	6.2
85	16X7	1 1/4	R	0.19	1.27	0.23	0.04	0.007	52,000	85,900	21.5	59,900	725	355	120	6.7
85	16X7	1 1/4	N	0.19	1.27	0.23	0.04	0.007	57,000	81,300	27.0	57,300	700	360	−50	6.7
86-1	12X7	1 1/4	R	0.16	1.23	0.34	0.06	0.010	52,900	77,100	25.5	58,000	835	455	80	7.7
86-2	13X7	1 1/4	R	0.16	1.23	0.33	0.07	0.010	53,200	76,900	25.0	61,500	965	495	90	7.7
86-2	13X7	1 1/4	N	0.16	1.23	0.33	0.07	0.010	52,800	73,200	29.5	58,500	1090	540	−60	7.7
87-1	11X7	1 1/4	R	0.17	1.20	0.24	0.05	0.008	54,900	79,500	24.5	62,800	1050	525	80	7.1
87-2	15X7	1 1/4	R	0.17	1.20	0.23	0.05	0.008	58,800	75,800	24.0	60,000	930	410	50	7.1
88	14X7	1 1/4	R	0.15	1.30	0.25	0.04	0.006	53,100	78,400	24.8	62,600	1110	570	70	8.7
89-1	10X7	1 1/4	R	0.20	1.20	0.26	0.05	0.010	42,900	71,500	25.0	58,600	765	345	60	6.0
89-2	9X7	1 1/4	R	0.19	1.18	0.30	0.05	0.011	55,500	77,300	25.0	57,000	785	370	15	6.0
90	20X7	1 1/4	R	0.13	1.01	0.25	0.04	0.007	47,400	66,900	28.0	56,200	1235	690	50	7.8
91	17X7	1 1/4	R	0.14	1.05	0.24	0.04	0.007	48,300	70,700	28.5	65,500	1700	710	45	7.5
92	5X7	1 1/4	R	0.19	1.29	0.27	0.05	0.010	56,900	81,600	38.0†	56,700	675	295	40	6.8
93-1	8X7	1 1/4	R	0.17	1.26	0.34	0.05	0.010	53,600	77,900	26.0	62,500	1150	500	10	7.4
93-2	7X7	1 1/4	R	0.17	1.26	0.24	0.05	0.009	54,700	77,100	24.0	60,600	1005	515	10	7.4
93-2	7X7	1 1/4	N	0.17	1.26	0.24	0.05	0.009	52,900	71,500	29.0	65,500	810	440	−40	7.4
94	6X7	1 1/4	R	0.19	1.27	0.28	0.05	0.010	61,200	81,800	47.0†	65,800	1135	565	−80	6.7

* Average of all tests conducted above transition temperature.
† Values marked with dagger represent % Elongation in 2 in.; all others in 8 in.

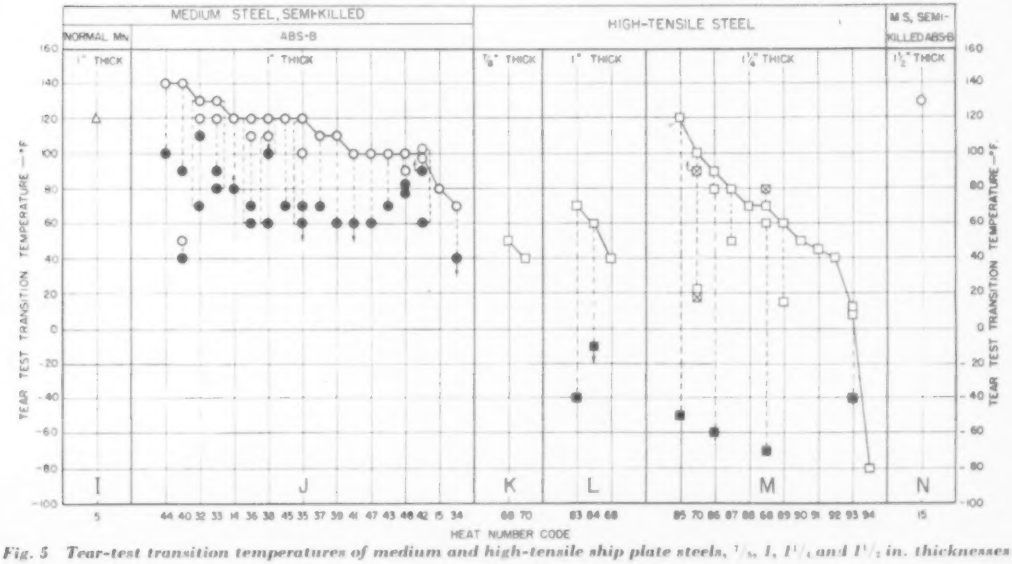

Fig. 5 Tear-test transition temperatures of medium and high-tensile ship plate steels, 7/8, 1, 1¼ and 1½ in. thicknesses

Solid points—normalized; x, shown in a square in illustration—stress relieved; all others, as-rolled

larly treated by the authors. The X, Y and Z symbols appearing in the plate code represent the production of three steel mills.

The data presented in Tables 1 to 5 are shown graphically in Figs. 3 to 7, inclusive, in which the tear-test transition temperatures are plotted against the heat code numbers arranged, in general, in descending order of transition temperature for each group of steels. The groupings in Figs. 3 to 5 were made on the basis of plate thickness and in Figs. 6 and 7 on the basis of type of steel. In Figs. 3, 4 and 5 the various types of steels are identified by different symbols, while in Figs. 6 and 7 the different symbols indicate various plate thicknesses. In the instances where the tear-test transition temperature was not fully established, the plotted points have been marked with upward- or downward-pointing arrows to indicate that the start of transition is either at the temperature shown or above or below, respectively. Detailed descriptions of the graphs follows:

(*a*) Figure 3 shows transition temperatures for $^1/_2$- and $^5/_8$-in steels: Section A covers three medium and two high-tensile steels; Section B, the $^5/_8$-in. semikilled medium steels of the ABS-B type; Section C, the $^5/_8$-in. fully killed medium steels; and Section D, the $^5/_8$-in.-thick high-tensile steels. There were no $^5/_8$-in. thick semikilled medium steels of normal manganese content (48-S-5) available for inclusion in this program.

(*b*) Figure 4 shows transition temperatures for $^3/_4$-in. medium steels; Section E covers the rimmed steels; Section F, the semikilled steels of normal manganese content; Section G, the semikilled steels of the ABS-B type, including the seven special aluminum-treated steels; and Section H, the fully killed steels. There were no $^3/_4$-in. thick high-tensile steels available for inclusion in this program.

(*c*) Figure 5 shows transition temperatures for $^7/_8$-, 1-, $1^1/_8$- and $1^1/_2$-in. steels: Section I covers the one 1-in. thick semikilled medium steel of normal manganese content; Section J, the 1-in. ABS-B type; Sections K, L and M, the $^7/_8$-, 1- and $1^1/_8$-in. high-tensile steels, respectively; and Section N, the one $1^1/_2$-in. thick ABS-B type.

(*d*) Figure 6 shows transition temperatures for all thicknesses of rimmed and semikilled medium steels: Section A covers the rimmed steels; Section B, the normal-manganese semikilled steels; and Section C, the semikilled ABS-B type steels and includes, for comparison purposes, the seven aluminum-treated S steels aligned with their companion coarse-grained steels.

(*e*) Figure 7: Sections D and E show transition temperatures for all thicknesses of fully killed medium and high-tensile steels, respectively.

DISCUSSION OF RESULTS

The data will now be discussed in relation to some of the basic variables which influence the notch-sensitivity characteristics of the steels investigated. Specifically, the data will be discussed from the standpoint of:

(*a*) Type of steel—Process and chemistry.
(*b*) Effect of plate thickness.
(*c*) Effect of heat treatment—stress-relieving and normalizing.
(*d*) Microstructure.

Type of Steel

A summary of the as-rolled tear-test transition temperatures of the various types of steels is presented in Table 6 in which, wherever available, are shown the number of samples tested and the high, average and low tear-test transition temperatures for each thickness category. Referring to the medium steel class it may be observed that, from the standpoint of tear-test transition temperature, the types of steels may be arranged in the following descending order of quality, based principally on the $^5/_8$ and $^3/_4$ in. thicknesses:

1. ABS-B, Al-treated (special)
2. Fully killed
3. ABS-B, semikilled
4. 48-S-5, semikilled
5. Rimmed

For a broader basis of comparison, items 1 and 2 may be classified as fully killed, items 3 and 4 are semikilled while Item 5 is the open or rimmed type. Thus,

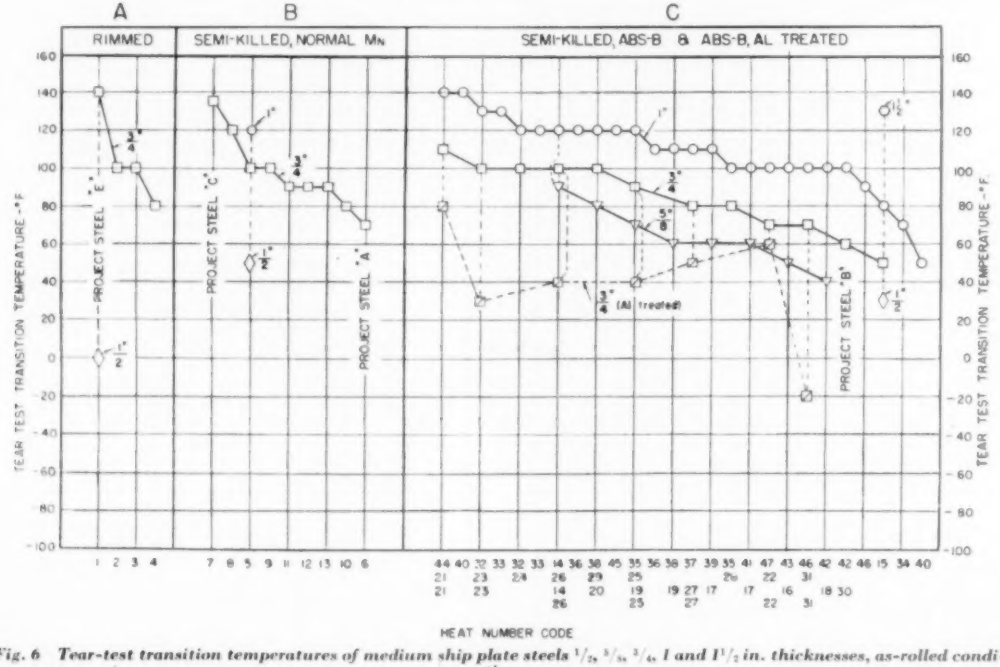

Fig. 6 Tear-test transition temperatures of medium ship plate steels $^1/_2$, $^5/_8$, $^3/_4$, 1 and $1^1/_2$ in. thicknesses, as-rolled condition

Table 6—Summary of Tear-Test Transition Temperatures, ° F. (As-Rolled Condition)

Type and process	*Distribution*	*Plate thickness, in.* 1/2	5/8	3/4	7/8	1	1 1/4	1 1/2
Medium, rimmed	No.*	1	...	4	...	...	...	...
	High	...	...	140	...	...	...	...
	Low	...	...	80	...	...	...	...
	Average	0	...	105	...	...	...	...
Medium, semikilled, 48-S-5	No.*	1	...	9	...	1	...	1
	High	...	...	135	...	...	...	...
	Low	...	...	70	...	...	...	...
	Average	50	...	97	...	120	...	130
Medium, semikilled, ABS-B	No.*	1	8	12	...	26	...	...
	High	...	90	110	...	140	...	...
	Low	...	40	50	...	50	...	...
	Average	30	64	84	...	108	...	...
Medium, ABS-B, Al-treated	No.*	...	...	7	...	...	...	...
	High	...	...	80	...	...	...	...
	Low	...	...	−20	...	...	...	...
	Average	...	...	40	...	...	...	...
Medium, fully killed	No.*	...	21	3	...	...	...	...
	High	...	90	60	...	...	...	...
	Low	...	30	50	...	...	...	...
	Average	...	58	57	...	...	...	...
High-tensile, vanity-type, fully killed	No.*	2	10	...	2	3	18	...
	High	30	130	...	50	70	120	...
	Low	−30	−50	...	40	40	−80	...
	Average	0	40	...	45	57	49	...

* Indicates number of samples on which definite transition temperatures were established.

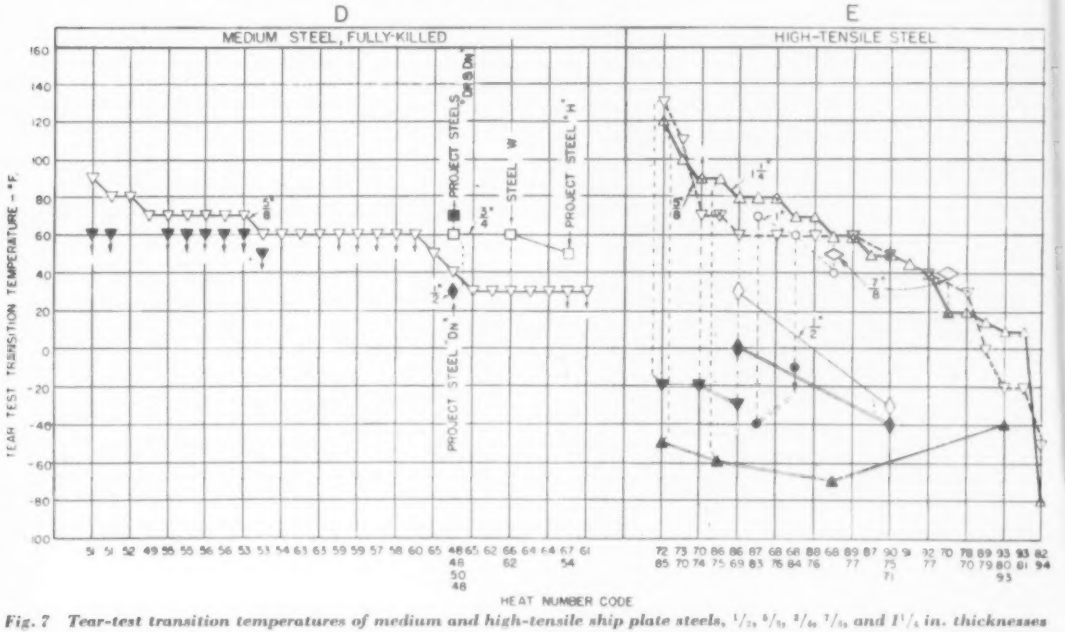

Fig. 7 Tear-test transition temperatures of medium and high-tensile ship plate steels, 1/2, 5/8, 3/4, 7/8, and 1 1/4 in. thicknesses

Solid points—normalized; x, in inverted triangle, or x, in triangle, in illustration—stress relieved; all others, as-rolled

Table 7—Ratio of Unacceptable Plates to Number Tested Based on a Minimum Acceptable Tear-Test Transition Temperature of 70° F. (As-Rolled Condition)

Type and process	*Plate thickness, in.* 1/2	5/8	3/4	7/8	1	1 1/4	1 1/2	*Total, all sizes of each type*
Medium, rimmed	0/1	...	4/4	...	...	...	...	4/5
Medium, semikilled, 48-S-5	0/1	...	8/9	...	1/1	...	...	9/11
Medium, semikilled, ABS-B	0/1	2/8	8/12	...	24/26	...	1/1	35/48
Medium, fully killed	...	1/21	0/3	...	...	...	...	2/25
Medium, ABS-B, Al-treated			1/7					1/7
High-tensile, vanity-type, fully killed	0/2	2/10		0/2	0/3	3/18	1/1	7/36
Total—each size of all types	0/5	7/48	21/59	0/2	24/30	3/18	1/1	
Total—all types and all sizes								59/126

there appears to be a gradual improvement in transition temperature with the extent of deoxidation. A comparison of item 1 vs. 2 and item 3 vs. 4 suggests an improvement due to a higher manganese content (0.60 to 0.90%). The best results appear to be derived from ABS-B steel produced with a fine-grain practice (aluminum-treated).

Comparing the high-tensile with the medium steel class, it is to be noted that the "high" in the high-tensile class is comparable to the "high" found in the medium rimmed and semikilled steels while the "low" is considerably below any of the medium steels. The averages for the high-tensile steels compare favorably with the fully killed medium steels, including the special ABS-B (aluminum-treated) type.

If project steel "A" with a transition temperature of 70° F. be considered of minimum acceptable quality for ship structures from the standpoint of notch-sensitivity and, as such, used as a basis for a specification requirement, the ratios of unacceptable plates to the total number tested in each category would be as given in Table 7. This tabulation serves to confirm the above discussion and demonstrates that the improvement from rimmed to semikilled 48-S-5 and from semikilled 48-S-5 to semikilled ABS-B is slight, while there are indications of pronounced improvement in the fully killed over the semikilled and rimmed medium steels.

Effect of Plate Thickness

The general trend as to the effect of plate thickness on the tear-test transition temperature of as-rolled material is illustrated in Figs. 6 and 7. It is to be observed from Section C of Fig 6 that an increase in plate thickness of medium steel is associated with an increase in transition temperature. However, in the case of high-tensile steel, as illustrated in Section E of Fig. 7, the relative effect of size is less pronounced in the light of the wide and overlapping ranges of transition temperature exhibited particularly by the $^5/_8$ and $1^1/_4$ in. thicknesses. The two $^1/_2$-in. thick plates fall considerably below the trend shown by all the other thicknesses.

The data include instances of plates in various thicknesses rolled from the same heat, from which a more direct concept of the effect of thickness on the transition temperature may be derived, as shown in Table 8.

Further reference to size effect is contained in Table 7, which indicates that the ratio of unacceptable plates to number tested increases, in general, with plate thickness. It should be noted that while the lowering of transition temperature with reduction in plate thickness is due, in part, to a change in specimen geometry, it is due mainly to metallurgical improvements derived from additional reduction and working in rolling and possibly by a faster rate of cooling from the finishing temperature.*

Table 8—As-Rolled Tear-Test Transition Temperatures in ° F. for Each Plate Thickness

Heat code	Type steel	Plate thickness, in. $^1/_2$	$^5/_8$	$^3/_4$	$^7/_8$	1	$1^1/_4$	$1^1/_2$
1	M. S., rimmed	0	..	140	..	..	..	..
5	M. S., S. K., 48-S-5	50	..	100	..	120	..	..
14	M. S., S. K., ABS-B	..	90	..	..	120	..	..
15	M. S., S. K., ABS-B	30	..	50	..	80	..	130
68	H. T. S.	..	..	..	50	40	60/70	..
69	H. T. S.	30	60	..	..	..	..	..
70	H. T. S.	..	..	..	40	..	20/100	..

Effect of Heat Treatment

The discussion on the effect of heat treatment is limited to (*a*) stress relieving and (*b*) normalizing.

(*a*) Stress relieving—Section M of Fig. 5 shows the effect of laboratory stress relieving on the transition temperatures of $1^1/_4$-in. thick high-tensile steel plates from heat codes 70 and 68. It will be noted that stress relieving did not materially influence the transition temperature. Figure 8 compares the as-rolled and stress-relieved transition temperatures of two $1^1/_4$-in. thick high-tensile steels, heat codes 68-1 and 70-2. The transition temperatures of mill stress-relieved plates ($^5/_8$ in. thick) fall in the approximate middle of the over-all range, as shown in Section D of Fig. 3.

(*b*) Normalizing—The effect of normalizing on the transition temperature has been investigated by the authors on the basis of laboratory heat treatment, specifically with a view of determining if any consistent improvement in notch-sensitivity characteristics may be derived from such treatment. Data on the normalized materials are contained in Tables 3, 4 and 5, and the effect of normalizing on the tear-test transition temperature is shown graphically in Figs. 3, 4 and 5. In these graphs, the solid points designate normalized transition temperatures and the broken vertical lines connect these with

* See Fig. 17 and discussion thereon in reference 3.

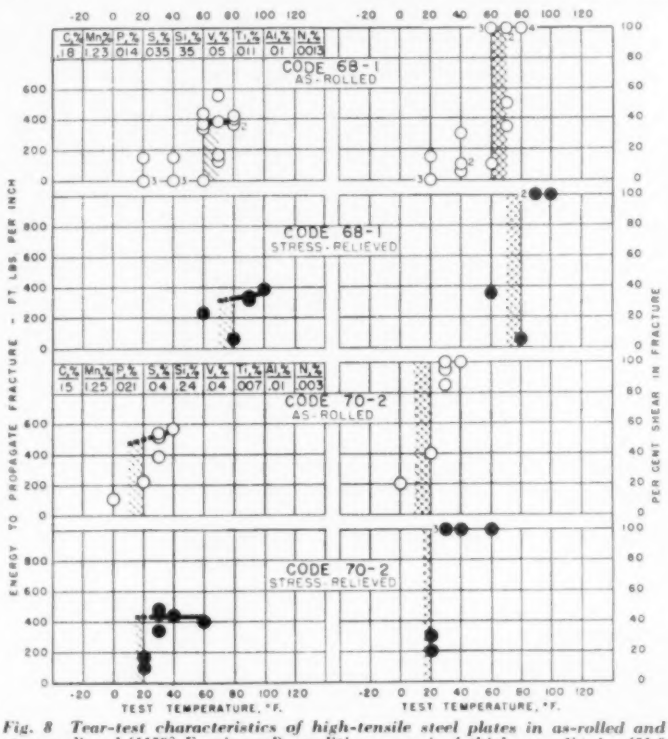

Fig. 8 Tear-test characteristics of high-tensile steel plates in as-rolled and stress-relieved (1150° F., air cool) conditions, nominal thickness—$1^1/_4$ in. (51.0 lb.)

130° F. 1½ in. thick (G8) 90° F. 1 in. thick (G7) 50° F. ¾ in. thick (G6) 30° F. ½ in. thick (G5)

Fig. 9 Photomicrographs of four plate thicknesses of a semikilled, medium steel, ABS-B type, as-rolled condition, heat code No. 15. Nital etch. 100 × Original Magn.
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the open points which represent the corresponding as-rolled transition temperatures.

In the case of medium steel, it is to be noted that:

1. The transition temperatures of the ⅝-in. semikilled steels of the ABS-B type (Section B, Fig. 3) were not materially improved by normalizing. Normalizing lowered the ratio given in Table 7 for this group from ²⁄₈ to ¹⁄₈.

2. The transition temperatures of the 1-in. semikilled steels of the ABS-B type (Section J, Fig. 5) were, with a few exceptions, appreciably improved by normalizing, evidenced by the fact that normalizing lowered the ratio given in Table 7 for this group from 24/26 to 10/26.

3. The transition temperatures of the ⅝-in., fully-killed steels (Section C, Fig. 3) were similarly improved by normalizing, as evidenced by the fact that normalizing lowered the ratio given in Table 7 for this group from 3/27 to 0/27.

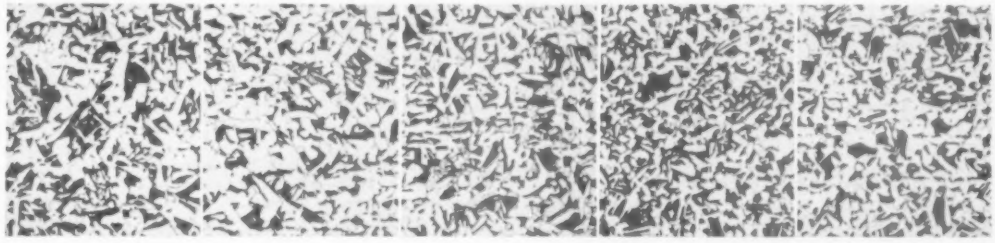
In the case of high-tensile steel, the effect of normalizing in improving the transition temperature was found to be more pronounced and more positive than in the case of medium steel. Specifically, in the ⅝-in. group (Section D of Fig. 3, the as-rolled transition temperatures of 130, 70 and 60° F. for steels 72, 74 and 69 were lowered to −20, −20 and −30° F., respectively. Similarly, in the 1-in. thick group (Section L, Fig. 5) the as-rolled transition temperatures of 70 and 60° F. of steels 83 and 84 were lowered to −60 and to −10° F. or below, respectively. Finally, in the 1¼-in. group (Section M, Fig. 5), the as-rolled transition temperatures of 120, 90, 60 and 10° F. of steels 85, 86, 68 and 93 were lowered to −50, −60, −70 and −40° F., respectively. The effect of normalizing high-tensile steel is strikingly illustrated in Fig. 2 which pertains to steel 85.

Microstructure

The microstructures of representative samples of some of the steels investigated have been studied with a view of determining the existence of any correlation between structure and tear-test transition temperature.

Figure 9 shows the microstructures of the four as-rolled thicknesses of heat code 15 which exhibited tear-test transition temperatures of 130, 80, 50 and 30° F. for the 1½-, 1-, ¾- and ½-in. plates, respectively. A progressive decrease in the ferrite grain size may be observed with decrease in plate thickness, which is in line with the corresponding decrease in transition temperature. However, all plates were observed to be coarse-grained under the McQuaid-Ehn test, the A.S.T.M grain size being 1–3 for the 1½-, 1- and ¾-in. plates and 1–4 for the ½-in plate.

Figures 10 and 11 present the microstructures of five pairs of the S-series steels, heat codes 26, 25, 27, 22 and 31. Each pair of plates represents coarse- and fine-grain ingot practice. Figure 10 shows the microstructures of the five plates rolled from ingots representing the regular semikilled practice which were reported by the



100° F. Heat 26(822) 90° F. Heat 25(813) 80° F. Heat 27(820) 70° F. Heat 22(821) 70° F. Heat 31(85)

Fig. 10 Photomicrographs of ¾-in. thick, medium steel plates of the ABS-B type. As-rolled condition, McQuaid-Ehn grain size 2–4. Nital etch. 100 × Original Magn.
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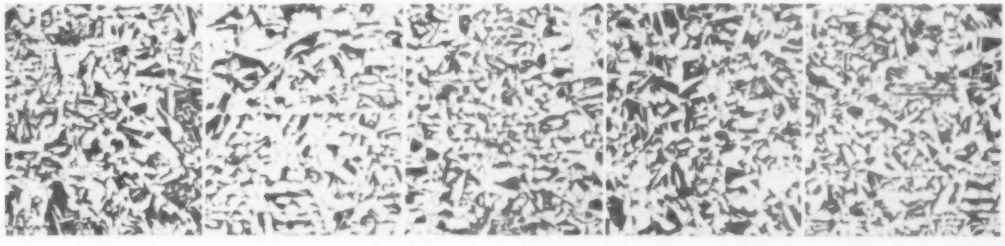

40° F. Heat 26(812) 40° F. Heat 25(817) 50° F. Heat 27(816) 60° F. Heat 22(814) −20° F. Heat 31(84)

Fig. 11 Photomicrographs of ¾-in. thick, medium steel plates rolled from aluminum-treated ingots of same heats indicated in Fig. 10. As-rolled condition, McQuaid-Ehn grain size 5–7. Nital etch. 100 × Original Magn.
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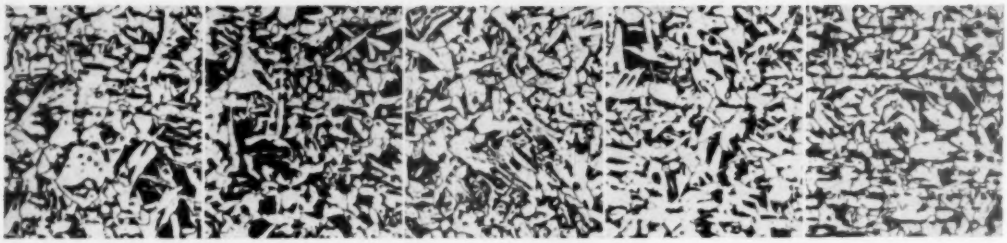

130° F. Heat 32-2 120° F. Heat 32-1 140° F. Heat 40-2 50° F. Heat 40-1 100° F. Heat 35-1

Fig. 12 Photomicrographs of 1-in. thick, semikilled, medium steel plates of the ABS-B type. As-rolled condition. Nital etch. 100 × Original Magn.

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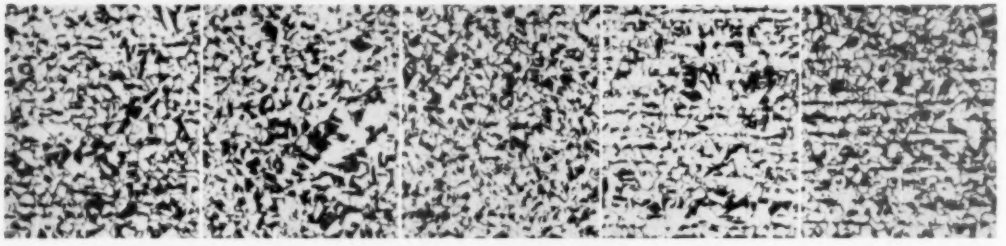

70° F. Heat 32-2 110° F. Heat 32-1 90° F. Heat 40-2 40° F. Heat 40-1 <70° F. Heat 35-1

Fig. 13 Photomicrographs of 1-in. thick, semikilled, medium steel plates of the ABS-B type, normalized condition. Nital etch. 100 × Original Magn.

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steel manufacturer as having a McQuaid-Ehn grain size of 2–4; the photomicrographs have been arranged in order of descending tear-test transition temperatures of 100, 90, 80, 70 and 70° F. Figure 11 shows the microstructures of the five plates rolled from companion ingots which were aluminum-treated in the mold for fine-grain, and the McQuaid-Ehn grain size of these was reported by the steel manufacturer as being 5–7. The arrangement of the photomicrographs parallels that of Fig. 10 with respect to heat code number; the corresponding transition temperatures are 40, 40, 50, 60 and −20° F. In this instance, the fine-grain practice resulting in a change in McQuaid-Ehn grain size from 2–4 to 5–7 effected a decrease in the tear-test transition temperature, the maximum change being 90° F. (heat 31) and the minimum being 10° F. (heat 22). However, the ferrite grain size does not correlate with the McQuaid-Ehn grain size or with the transition temperatures.

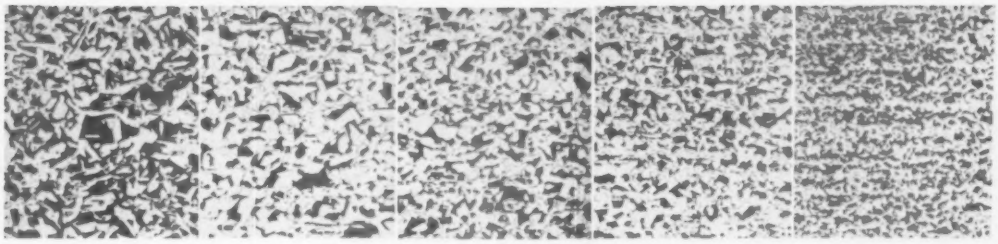
The microstructures of five of the 1-in. thick, semikilled medium steel plates of the ABS-B type were examined in the as-rolled and normalized conditions and are shown in Figs. 12 and 13, respectively. The photomicrographs in the same line represent two different plates from the same heat. As illustrated in Fig. 12, there appears to be no correlation between the ferrite grain size of the as-rolled material and the transition temperature; for example, plates 1 and 2 from heat code 40 showed widely different transition temperatures without exhibiting any appreciable differences in ferrite grain size and microstructure. Normalizing effected a considerable refinement in grain size, as shown in Fig. 13. The transition temperature in all cases was lowered by normalizing. The reduction, which was slight in some cases and appreciable in others, does not correlate with the change in microstructure; for example, the refinement in ferrite grain size of heat codes 32-1 and 40-1 was associated with a drop in transition temperature of only 10° F. whereas in heat codes 32-2, 40-2 and 35-1, the drop amounted to 50° F. and over. In addition, heat code 40-2 shows a somewhat finer and more uniform microstructure than 40-1 in the normalized condition, but the former exhibited a transition temperature of 90° F. as against 40° F. for the latter.

The microstructures of five of the 1¼-in. thick high-tensile steels of widely varying as-rolled transition temperatures were studied in the as-rolled and normalized conditions. These are shown in Figs. 14 to 17 at magnifications of 100 X and 250 X. In Figs. 14 and 16, the photomicrographs representing the as-rolled condition have been arranged in order of decreasing transition temperatures of 120, 90, 60, 10 and −80° F. A progressive decrease in the ferrite grain size may be observed which corresponds to the decrease in transition temperature. The steel which exhibited the unusually low transition temperature of −80° F. also exhibited an extremely fine ferrite grain size. However, the McQuaid-Ehn grain size of all of these plates was approximately the same, namely 7–8. Figures 15 and 17 show the microstructures of these steels as observed in samples taken from laboratory-normalized tear-test specimens; the arrangement of the photomicrographs parallels that of Figs. 14 and 16, respectively, with respect to heat numbers. The normalized microstructures show a uniform, very fine-grain structure simulating that of steel heat 94 in the as-rolled condition. This refinement in grain size is accompanied by a marked suppression in transition temperature to a region of −40 to −70° F., as indicated below:

	Tear test transition temperature, ° F.	
Heat code	*As-rolled*	*Normalized*
85	120	−50
86-2	90	−60
68-2	60	−70
93-2	10	−40
94	−80	*

* Not tested because of lack of material.

While the above plates exhibited wide differences in the as-rolled transition temperature and ferrite grain size, the transition temperatures and the ferrite grain sizes after normalizing fall within relatively narrow limits.



120° F. Heat 85 90° F. Heat 86-2 60° F. Heat 68-2 10° F. Heat 93-2 −80° F. Heat 94

Fig. 14 Photomicrographs of 1¼-in. thick, high-tensile steel plate, as-rolled. Nital etch. 100 × Orginal Magn.
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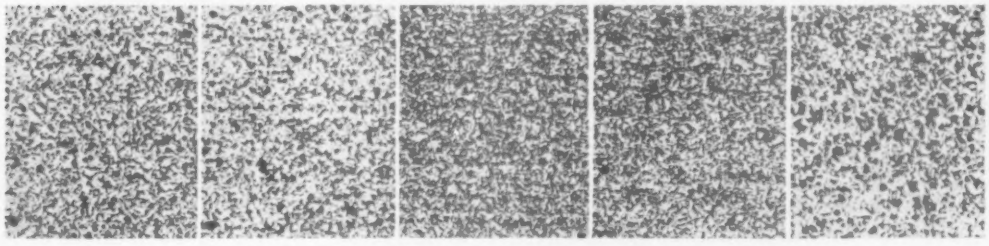

−50° F. Heat 85 −60° F. Heat 86-2 −70° F. Heat 68-2 −40° F. Heat 93-2 Heat 94

Fig. 15. Photomicrographs of 1¼-in. thick, high-tensile steel plate, normalized. Nital etch. 100 × Original Magn.
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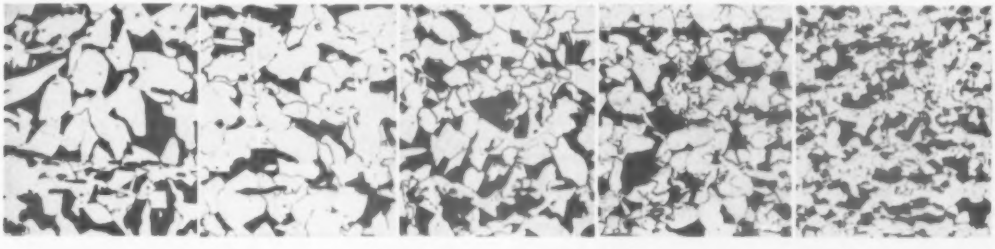

120° F. Heat 85 90° F. Heat 86-2 60° F. Heat 68-2 10° F. Heat 93-2 −80° F. Heat 94

Fig. 16 Photomicrographs of 1¼-in. thick, high-tensile steel plate, as-rolled. Nital etch. 250 × Original Magn.
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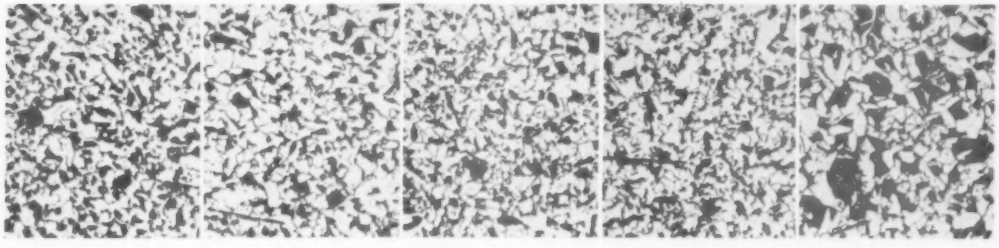

−50° F. Heat 85 −60° F. Heat 86-2 −70° F. Heat 68-2 −40° F. Heat 93-2 Heat 94

Fig. 17 Photomicrographs of 1¼-in. thick, high-tensile steel plate, normalized. Nital etch. 250 × Original Magn.
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SUMMARY

The tear-test characteristics and other properties of numerous current production heats of medium and high-tensile steel plate have been presented and discussed from the viewpoint of mill practice, chemistry and the effect of plate thickness, heat treatment and grain size. Data on a few special heats of medium steel have been included in order to supplement the findings derived from the regular run-of-the-mill heats. The characteristics of the so-called project steels have also been included as an aid in the evaluation of the new data.

The following summarizes the pertinent findings on medium steel plate:

(*a*) Considering all types and plate thicknesses, approximately 50% of the samples tested in the as-rolled condition fell below the quality of Project Steel "A" with respect to tear-test transition temperature.

(*b*) Normalizing is a partial corrective measure in lowering the transition temperature in that its effect was not consistent and the degree of lowering did not invariably approach the transition temperature level of Project Steel "A."

(*c*) From the standpoint of notch-sensitivity characteristics, as evaluated by the tear test, there appears to be a gradual improvement with the extent of deoxidation.

(*d*) The tear-test transition temperature decreases with decreasing plate thickness because of specimen geometry and principally because of metallurgical improvements.

(*e*) There was no consistent correlation between grain size and transition temperature except in the instance of four thicknesses rolled from the same heat.

The following summarizes the pertinent findings on high-tensile steel plate:

(*a*) Considering all plate thicknesses, approximately 20% of the samples tested in the as-rolled condition fell below the quality of Project Steel "A" with respect to tear-test transition temperature, in spite of the fact that service applications may place this type of steel in a category demanding notch-sensitivity characteristics superior to those of medium steel.

(*b*) Normalizing is a positive measure for improving the notch-sensitivity characteristics in that it consistently suppresses the tear-test transition temperature to levels considerably below that established for Project Steel "A."

(*c*) The effect of plate thickness on the transition temperature is not as significant as in the case of medium steel.

(*d*) The ferrite grain size of the as-rolled material correlates closely with the transition temperature in that the finer the grain size, the lower the transition temperature. Normalizing effects a refinement of grain size, the degree of which is more pronounced the coarser the original grain size.

ACKNOWLEDGMENT

The authors desire to express their appreciation to the Bureau of Ships of the Navy Department and the Ship Structure Committee for continuing this program, providing contact with other collaborating activities and permission to publish this paper. They are grateful to Capt. D. C. Redgrave, U.S.N., Director of the Material Laboratory, New York Naval Shipyard, for his encouragement and review of the paper. Thanks are also due to A. Chick, J. J. Gabriel and other associates of the authors for assistance rendered in obtaining the test data.

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Low-Carbon Stainless Steels Minimize Intergranular Corrosion

Carnegie-Illinois Steel Corp., a United States Steel Subsidiary, announces that it is prepared for commercial production of low-carbon (0.03% max.) stainless steels. These new steels, which are especially useful in industry, are made possible through mastery of the details of production and increased knowledge of the basic nature of intergranular corrosion.

Up to the present it has been necessary to add columbium or titanium to austenitic stainless steels as "stabilizers" to minimize the adverse effects of carbon and thereby render the alloy less susceptible to intergranular corrosion. The supply of these elements is sometimes critical. Consequently conservation is served by avoiding their use unless absolutely necessary.

Recognizing this problem, as early as 1939, Carnegie-Illinois began investigations to determine a practical means to manufacture commercially chrome-nickel stainless steels with the lowest possible level of carbon. Concurrently with the development of manufacturing techniques, extensive corrosion-testing programs were set up in Carnegie-Illinois laboratories and in the laboratories of principal customers for this type of steel.

It has taken a decade to prove that the manufacturing techniques are economically sound and to accumulate sufficient corrosion-testing data to justify consumer acceptance of 0.03% maximum carbon stainless steels for use in many applications in which columbium or titanium stabilized stainless steels were formerly used. Moreover, the testing program has indicated that, on the basis of established standards, the 18–8 steels containing not more than 0.03% carbon have a resistance to intergranular corrosion equivalent to that of 18–8 columbium and titanium stainless steels.

Welding tests have confirmed these results and demonstrated that the low-carbon 18–8 materials can replace the stabilized types for those applications, such as welding, that involve short heating times in the sensitizing temperature range.

A.S.T.M. Symposium on Deformation of Metals as Related to Forming and Service

This A.S.T.M. symposium (Special Technical Publication No. 87) focuses attention on recent developments dealing with some of the more fundamental studies of plastic deformation and flow. The last few years have witnessed much progress in developing a more rational and fundamental concept of metal flow and fracture. The approaches vary from the more academic hypotheses and theories of the physical metallurgist and physicist to those of the works metallurgist in his laboratory and plant.

Cognizance of abstract terms, such as biaxial and triaxial stresses, stress patterns and deformation rates, has fostered critical surveys of metal fabrication and failure. This has resulted in a number of new tests which accomplish two things of basic import. First, they closely simulate actual service conditions as these factors are analyzed in terms of present knowledge; and, second, they provide the proving ground between the theory and practice in, and more intelligent application of, metals for structural uses.

The five technical papers in this symposium cover tests of ductility in ship structure; notch-sensitivity of ship plate-correlation of laboratory-scale tests with large-scale plate tests; measurement of ductility in sheet metals; hydraulic bulge testing of sheet metals and notched-bar tension tests on annealed carbon-steel specimens of various sizes and contours.

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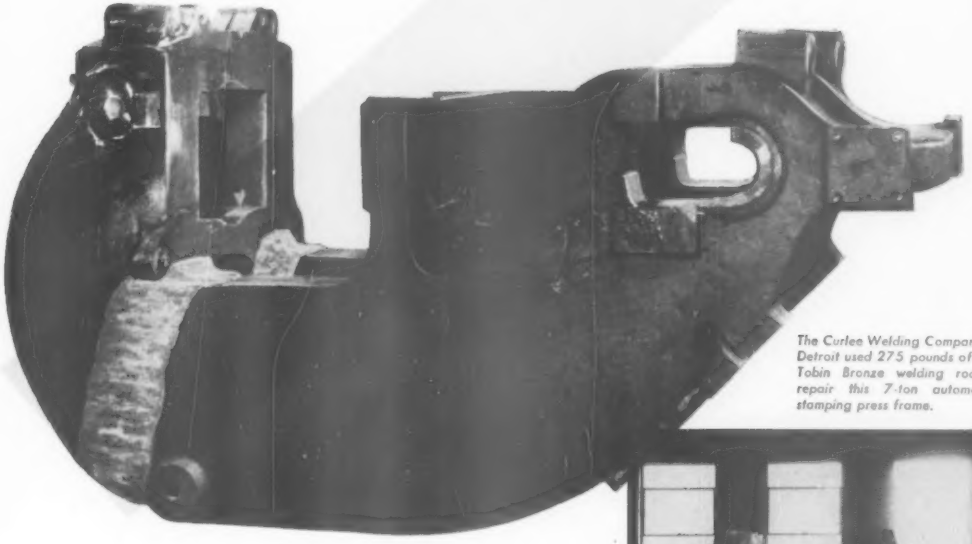

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